WATER QUALITY MANAGEMENT OF BILGE WASTES AT PEARL HARBOR, HAWAII

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ABSTRACT

The Navy requires a new method to collect and treat the bilge waste discharged from U.S. Navy Ships. This thesis recommends an interim plan, which can be implemented in a relatively short time frame, and a permanent plan which will take several years to implement. Although a permanent solution is recommended, the focus of this thesis is on what can be done now (interim plan) to collect and treat the bilge waste. The interim plan calls for collection of the bilge waste using pump trucks and barges. The collected bilge waste would then be processed by an oil/water separator, with the separated oil being recycled. The non-oily, separator effluent would then be prefiltered and processed through a reverse osmosis unit.

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LIST OF ABBREVIATIONS

Abbreviation	Definition
CPI	Corrugated Plate Interceptor
gpd	Gallons Per Day
gpm	Gallons Per Minute
IWWTP	Industrial Wastewater Treatment Plant
mg/l	Milligrams Per Liter
NPDES	National Pollution Discharge Elimination System
NSC	Naval Supply Center
OWS	Oil/Water Separator
PPI	Parallel Plate Interceptor
ppm	Parts Per Million
SWCAS	Ships Wastewater Collection Ashore System
SWOB	Ships Waste Oil Barge
TTO	Total Toxic Organics
USEPA	United States Environmental Protection Agency
WWTP	Wastewater Treatment Plant

PREFACE

All ships generate bilgewater. The U.S. Navy has a long history of using floating oil/water separators (known as "donuts") to process the bilgewater discharged from its ships. Recently, the U.S. Navy has become increasingly concerned over adequacy of donuts in keeping pollutants from entering into the surrounding waters. As a result the Navy has begun to investigate alternatives to the use of donuts. This thesis is intended to augment that effort by estimating the amount of bilgewater generated at Pearl Harbor over time and recommending a course of action to replace the donuts.

CHAPTER 1
INTRODUCTION

1.1 Background and Definitions

Improving and maintaining the quality of U.S. waters is stated as a National Goal in the Federal Water Quality Act of 1987 (Anderson, Mandelker, Tarlock 1990). U.S. Navy operations in these waterways have a significant impact on the water quality.

"Bilge waste" is discarded bilgewater. All ships' compartments must have drains for any liquid in the compartment to escape. Most of these drains lead directly into the bilge. A ship's bilge is defined as the interior region within the ship's hull that exists between the lowest point and the bottom of the vertical sides of the ship. (Essentially the region from the greatest curvature of the hull downward.) All the drained liquid that accumulates in the bilge is therefore called "bilgewater." These liquids originate from condensate on the ship's hull, spilled solvents or fuels/oil, seawater leaked from heat exchangers, and a combination of liquids leaked from machinery and equipment. Additionally, rust and dirt also get into the ship's bilgewater. This accumulated mixture of liquids (bilgewater) remains stored in the bilge until the bilge becomes full and must be emptied.

All ships generate bilgewater, whether at sea or not. On the average, Navy ships generate from 3700 gpd (for most surface combatants) to 50,600 gpd (for aircraft carriers and oil replenishing ships) of bilge water.

The Navy Public Works Center, San Diego conducted an analysis of 1 gallon grab-samples of various ships' bilge water. Additionally, the David Taylor Research Center (Annapolis, Md.) has been conducting bilgewater analysis over the last 10 years. The results of these analyses show that bilgewater is composed of a mixture of seawater and freshwater (95 to 99%), with oil and other contaminants accounting for the remaining portion. The oil found in bilgewater exists both as free and emulsified oils. The other contaminants include trace amounts of metals and other priority pollutants.

1.2 Current Navy Bilge Waste Management Practice

Navy management of bilge water varies slightly from port to port depending on the resources available. At Pearl Harbor, the ships pump their bilgewater directly from the ship into a "donut." The term "donut" is given to floating oil recovery rafts (Figure 1), which are designed to remove the oil from the bilgewater. As the oily water enters the waterborne donut, the oil fraction rises to the top of the donut and the water fraction mixes with and displaces the harbor water already inside the donut. The maximum allowable depth for the floatable oil is 5 feet. This equates to 9,000 gallons of bilgewater. There are two types of donuts used, open-bottom and closed-bottom. The open-bottom donut (Figure 1.1) allows the displaced water to exit the donut via oblong holes in its bottom. In a closed-bottom donut (Figures 1.2 - 1.4) the displaced water is

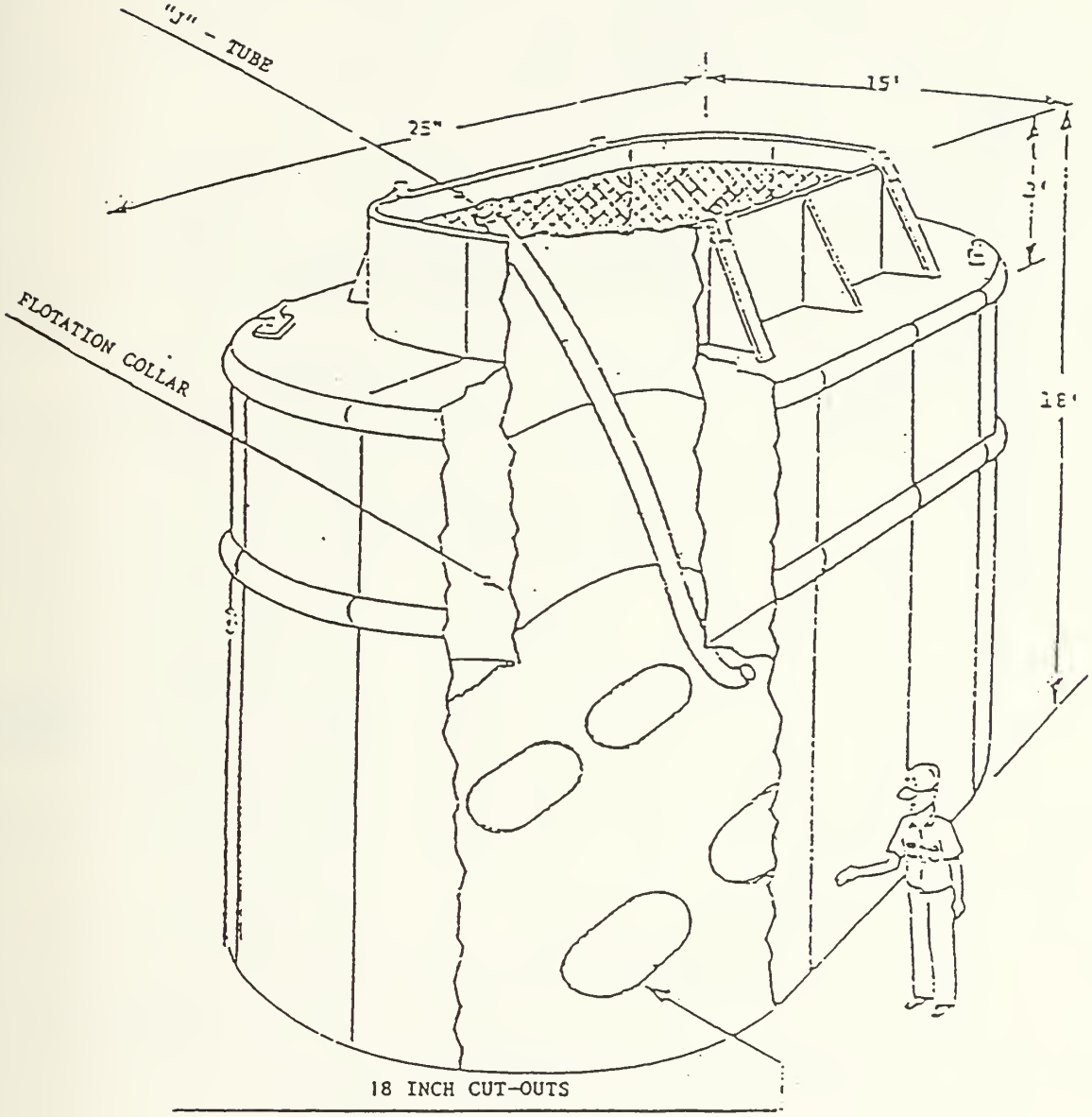

Figure 1.1

Open-Bottom Donut

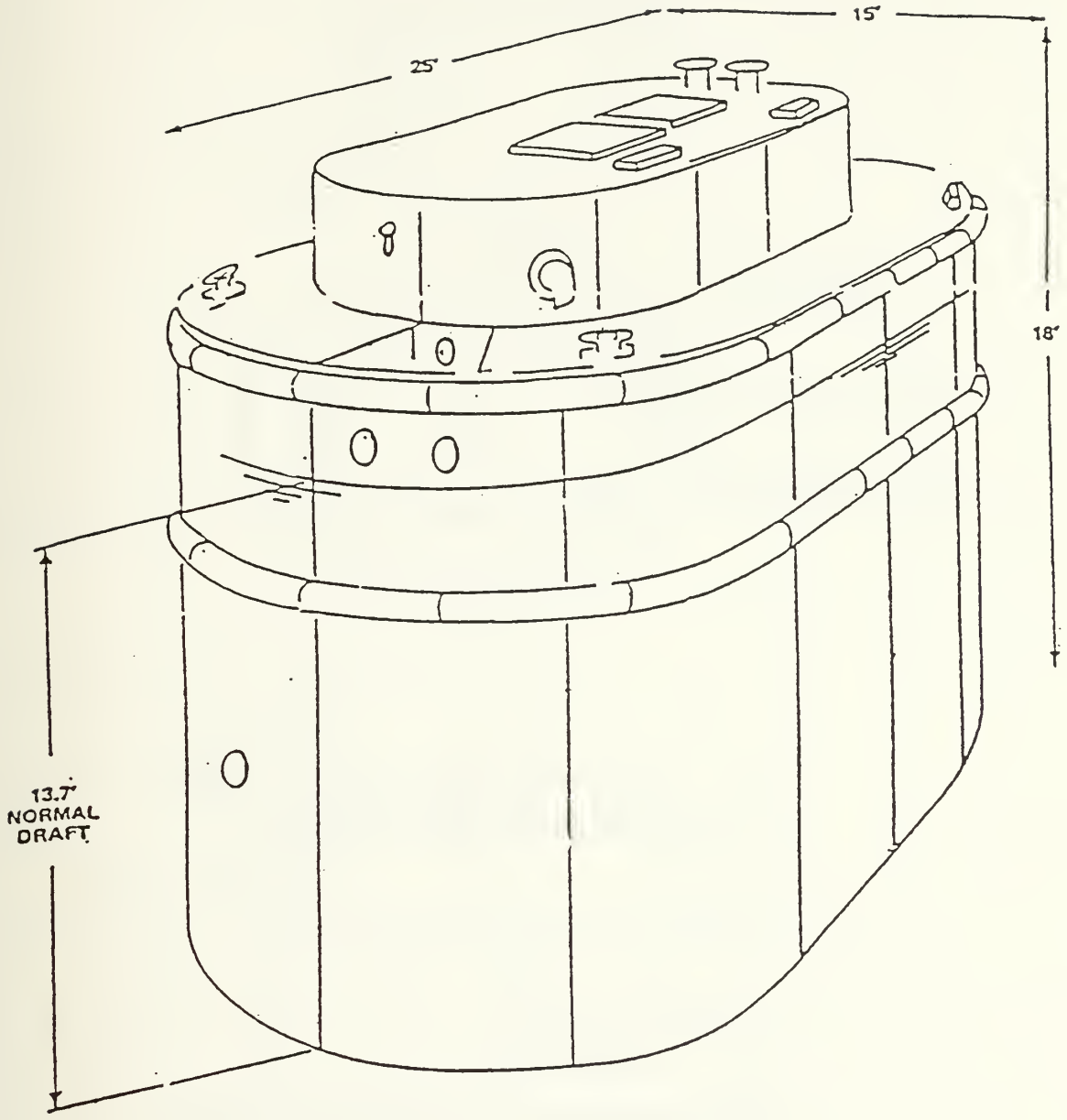

Figure 1.2

Isometric of Closed-Bottom Donut

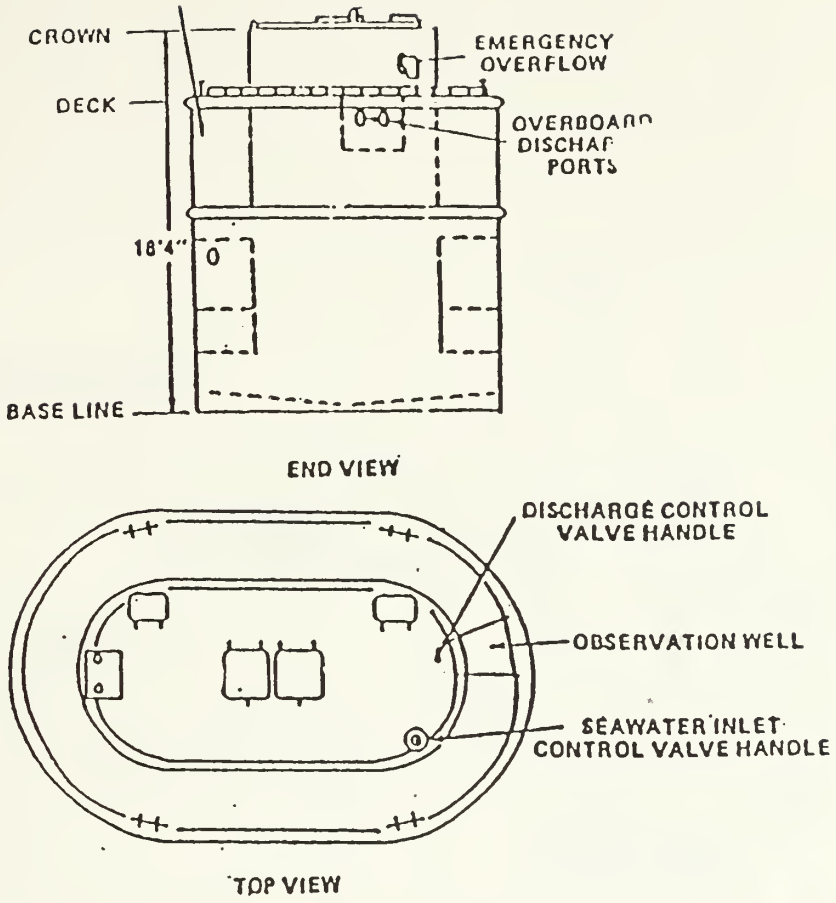

Figure 1.3

Interior Details of a Closed-Bottom Donut

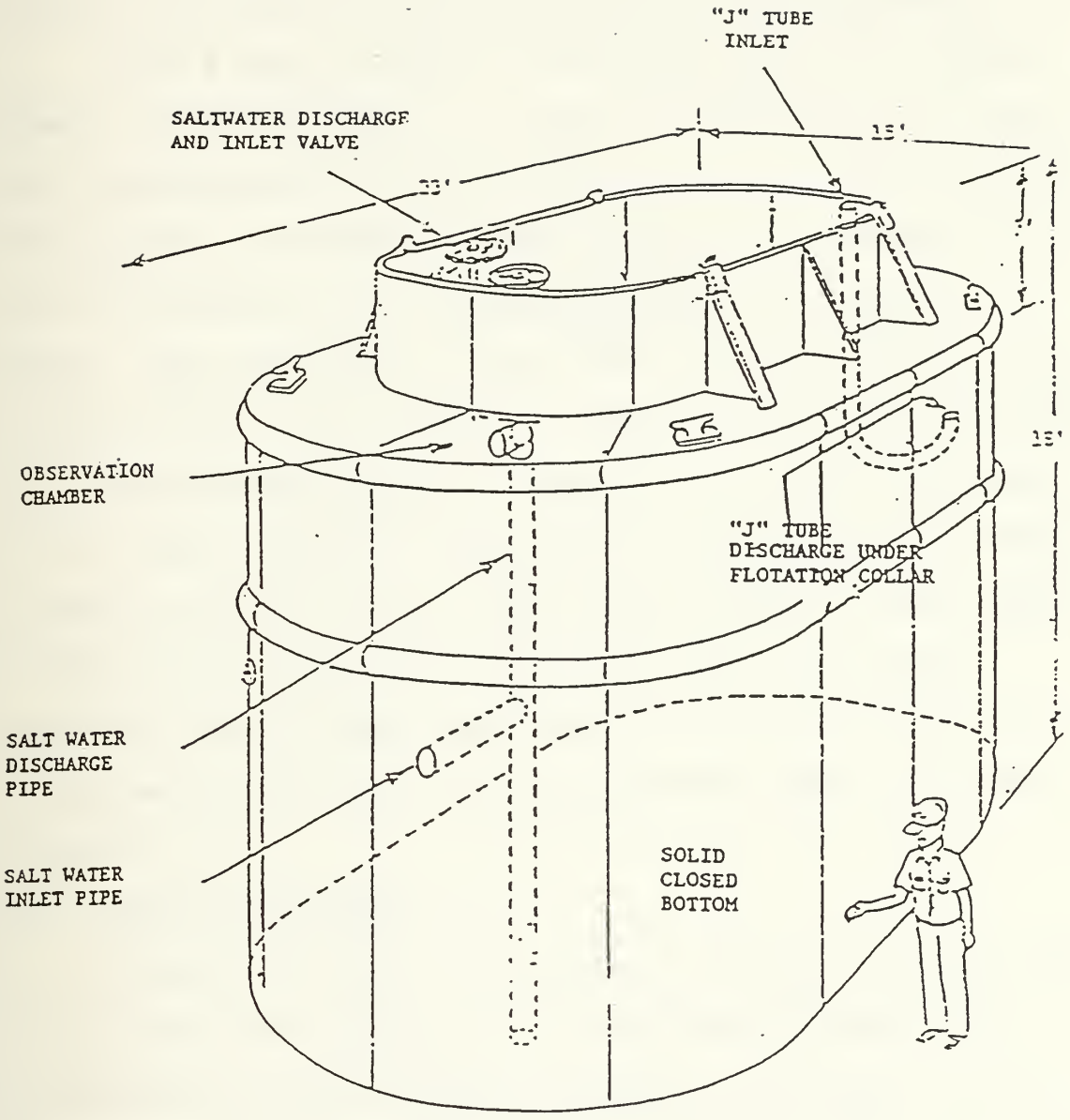

Figure 1.4

Closed-Bottom Donut

forced from the bottom of the sealed donut up a pipe to be discharged into the harbor. A closed-bottom donut's discharge of saltwater is regulated by a discharge control valve to be equal to the inflow rate of the bilgewater.

Once a donut is full, it is then floated to a Ships' Waste Oil Barge (SWOB). If the oil in the donut is found to be "reclaimable," then the floating oil is pumped into the designated "reclaimable" SWOB. If the oil is found to be non-reclaimable, it is pumped into the "non-reclaimable" SWOB. When the SWOBs are full they are taken to the Naval Supply Center (NSC) directly. NSC recycles the reclaimable oil and contracts for the disposal of the non-reclaimable oil. This process is summarized in the process flow chart shown as Figure 1.5. The Navy Supply Center at San Diego, North Island Naval Air Station, and 32nd Street Naval Station (the San Diego Naval Complex) currently utilize a management plan similar to Pearl Harbor's which is shown in Figure 1.6.

1.3 Problem Statement

Concern that the use of donuts allows pollutants within the bilge waste to escape from the donut and enter the surrounding natural waters has prompted the Chief of Naval Operations, in a message dated 08 April 1991, to order that the Navy "phase-out" the use of donuts. However, the use of donuts can not be "phased-out" until an acceptable alternative is in-place. All Naval ports were tasked to

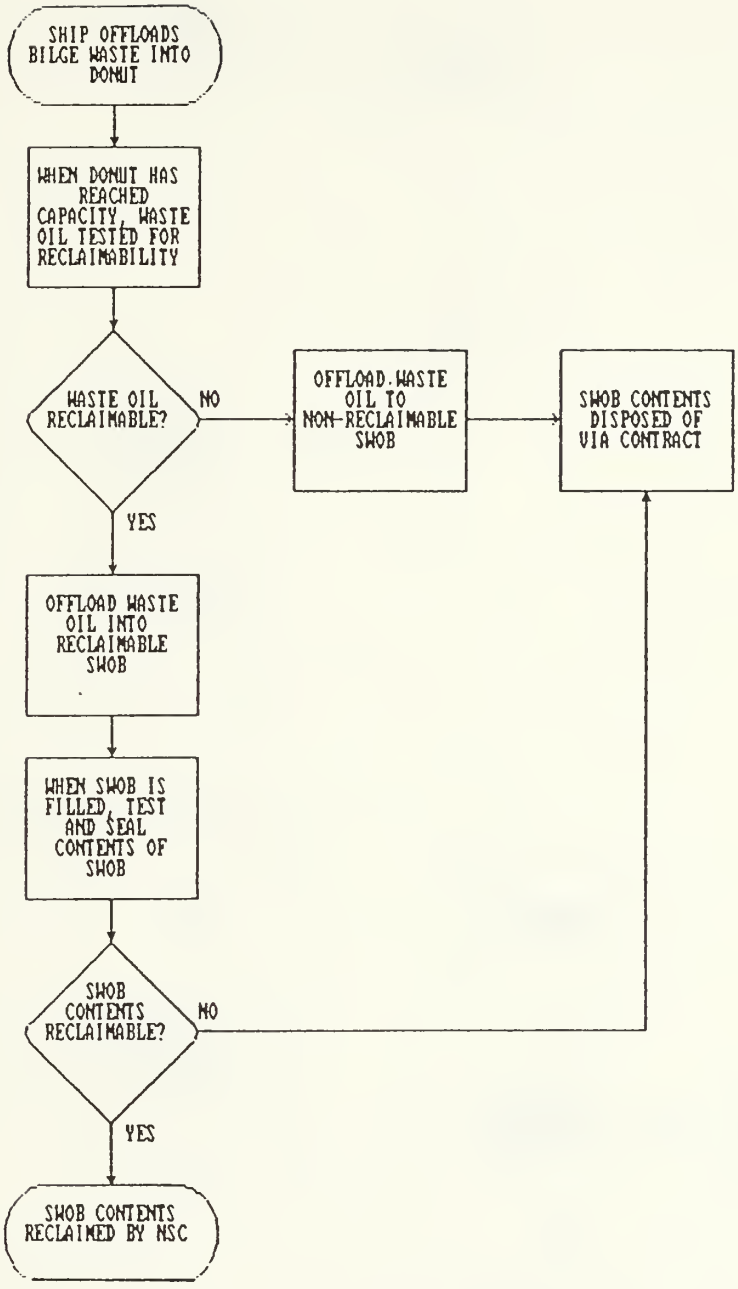

Figure 1.5

Current Bilge Waste Management Practice at Pearl Harbor

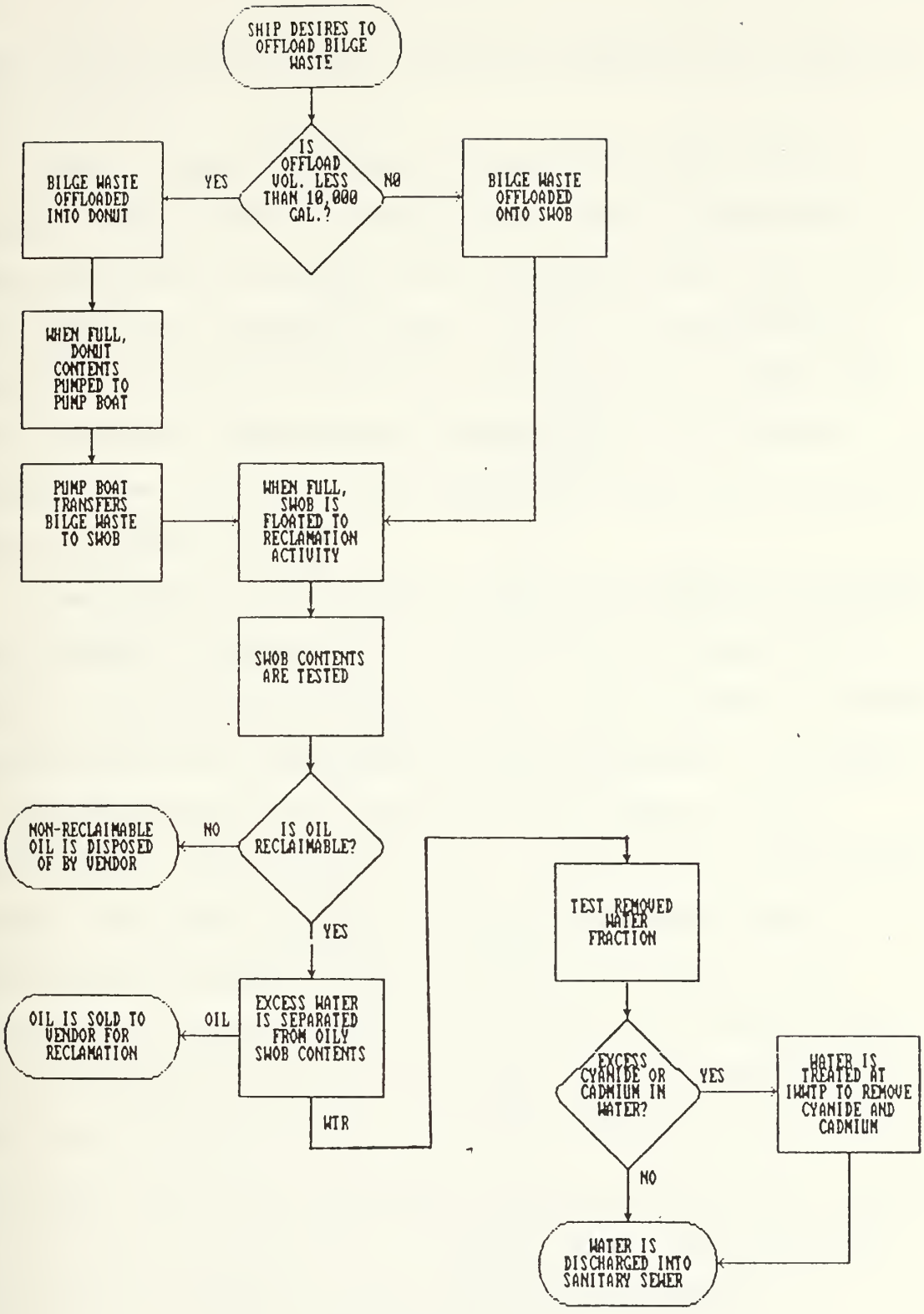

Figure 1.6

Bilge Waste Management Practices at San Diego

begin immediately to find a suitable alternative to the use use of donuts.

The U.S. Navy requires an alternative that can be quickly implemented, to minimize any further degradation of receiving waters, as well as an alternative that will serve its funtion for decades to come. Thus, it was desired to develop an interim ("quick-fix") alternative to donut use and a permanent (long-range) alternative to the use of donuts. The San Diego Navy Complex has proposed a solution shown in Figure 1.7.

The purpose of this thesis was to develop both interim and permanent alternatives to use of donuts in the water quality management of bilge wastes at Pearl Harbor. Various alternatives were formulated and then evaluated, in Chapter 4. Evaluation of the alternatives were based on cost, performance, and time required to implement the alternative method. The most economical interim alternative was identified in Chapter 5, and a bench-scale test of the alternative treatment method was conducted to analyze its actual performance in treating bilge waste. Additionally, detailed cost data for the interim alternative was developed. The most economical permanent alternative system to the use of donuts was also identified. The design and expected performance of the recommended permanent alternative method is detailed in Chapter 6.

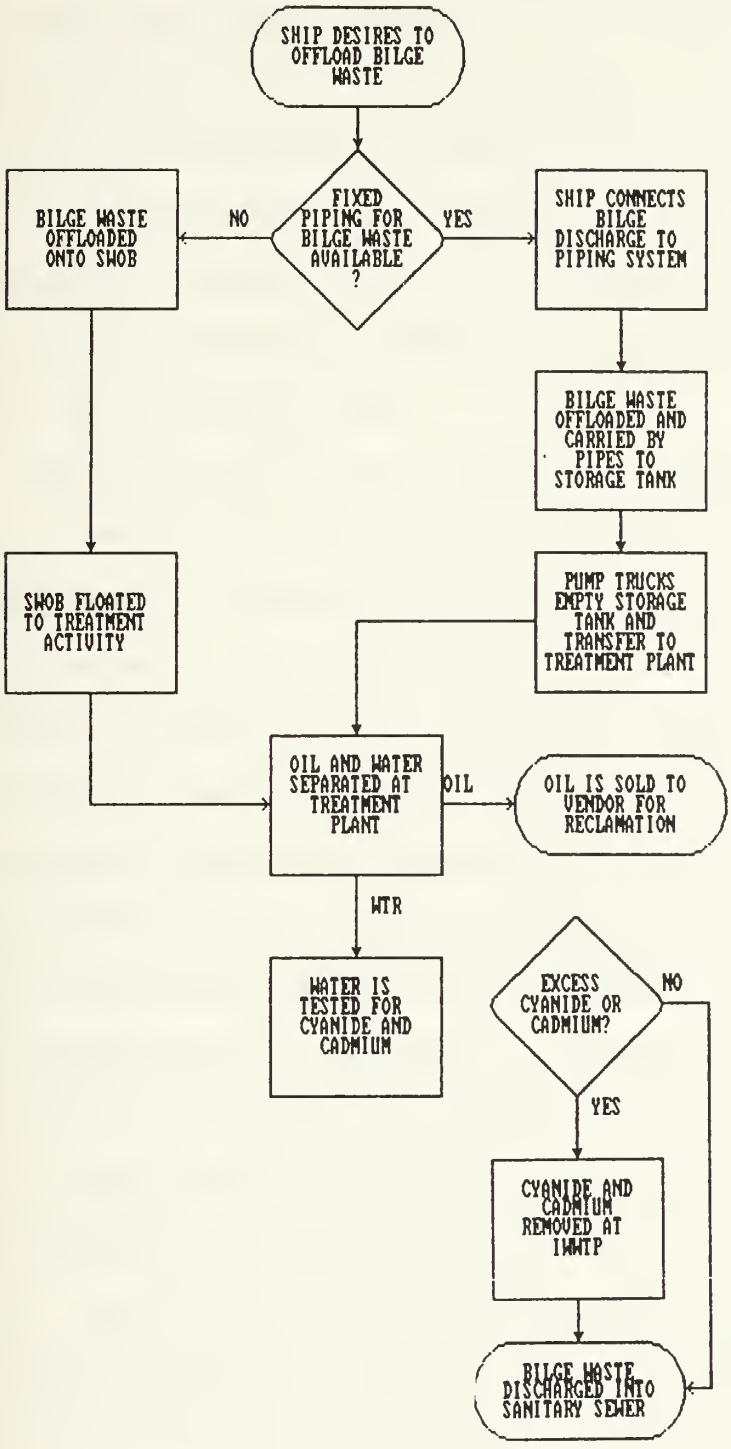

Figure 1.7

Proposed Bilge Waste Management for San Diego

CHAPTER 2
BILGE WASTE CHARACTERIZATION

2.1 Bilge Waste Constituents

Bilge water is a 95 - 99% mixture of seawater and non-seawater. The remaining portion of the bilge water consists of oil and other impurities, generally trace amounts of metals and solvents. Prior to treatment, bilge water is generally considered as either oily waste or, in some states, as hazardous waste.

Table 2.1 details the constituents found in bilge waste. The results were derived from 11 U.S. Navy ships of various types. Although the U.S. Navy does operate nuclear-powered vessels, the bilge waste was not analyzed for the presence of radionuclides. Secondary containment and engineering safeguards prevent the radionuclides from entering the bilgewater. Appendix A lists all the contaminants for which the bilge waste was tested.1 Table 2.1 also includes the Reportable Quantities, as dictated by the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA). Any accidental release of the listed contaminants in excess of the reportable quantities must be reported immediately to the National Response Center. (Note that 1,1,1-trichlorethene concentrations exceed the reportable quantity limits, and the high-end of

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1Data taken from a currently unpublished study performed by the Naval Surface Warfare Center, Caderock Division Detachment, Environmental Protection Branch (formerly, David Taylor Research Center).

Table 2.1
Concentration Ranges of Priority Pollutants
Found in Bilgewater and USEPA Reportable Limits
(mg/l)

ACID COMPOUNDS:

Contaminant	Range*	R.Q. Limit**
2,4-dichlorophenol	0.0110	1
2,4-dimethylphenol	0.03793	1
4-nitrophenol	0.010	1000
phenol	0.015 - 0.023	1000

BASE/NEUTRAL:

Contaminant	Range	R.Q. Limit
acenaphthene	0.013 - 0.043	1
acenaphthylene	0.015	1
anthracene	0.022	1
bis (2-chloroethoxy) methane	0.026	1
bis (2-ethylhexyl) phthalate	0.0112- 0.129	1
2,4-dinitrotoluene	0.031	1000
fluoanthene	0.016	1
fluorene	0.010 - 0.100	1
naphthalene	0.019 - 0.160	5000
N-nitrosodimethylamine	0.014 - 0.074	1
phenanthrene	0.0237- 5.0	1
pyrene	0.019	1
1,2,4-trichlorobenzene	0.0283	1

PESTICIDES:

Contaminant	Range	R.Q. Limit
aldrin	0.000041 - 0.0218	1
-BHC	0.000037 - 0.0117	1
-BHC	0.000079 - 0.012	1
-BHC	0.00006 - 0.0466	1
-BHC	0.000129 - 0.0106	1
4,4'-DDT	0.000165 - 0.0149	1
4,4'-DDE	0.000152 - 0.00156	1
DDD	0.000319 - 0.00452	1
dieldrin	0.000577 - 0.0108	1
-endosulfan	0.000039 - 0.00809	1
-endosulfan	0.000148 - 0.00830	1
endosulfan sulfate	0.000239 - 0.0908	1
endrin	0.000174 - 0.0168	1
endrin aldehyde	0.000245 - 0.0144	1
heptachlor	0.000183 - 0.0930	1
heptachlor epoxide	0.000047 - 0.0123	1
PCBs (Total)	0.11004 - 0.12021	10

VOLATILES:

Contaminant	Range	R.Q. Limit
chloroform	0.021	5000
ethylbenzene	0.0822	1000
1,1,1-trichloroethane	6.0 - 45.0	1

Table 2.1 (Continued)
Concentration Ranges of Priority Pollutants
Found in Bilgewater and USEPA Toxicity Limit
(mg/l)

OTHER TOXINS (metals, cyanide, total phenols)		
Contaminant	Range*	R.Q. Limit**
metals:		
arsenic	0.001 - 0.028	1
beryllium	0.0003	1
cadmium	0.005 - 0.178	1
chromium	0.02 - 0.77	1
copper	0.32 - 6.4	1
lead	0.02 - 2.90	1
mercury	0.0002- 0.0009	1
nickel	0.06 - 3.5	1
selenium	0.002 - 0.04	1
silver	0.01 - 0.08	1
thallium	0.02 - 0.05	1
zinc	0.08 - 16.2	1
cyanide	0.01 - 0.17	1
total phenols	0.01 - 2.6	1000
OTHER POLLUTANTS		
Contaminant	Range	R.Q. limit
oil/grease	10 - 5224	N/A

*Data taken from a currently unpublished study performed by the Naval Surface Warfare Center, Caderock Division Detachment, Environmental Protection Branch (formerly, David Taylor Research Center).

**Federal Regulation, 55 FR 51707,"EPA Designation, Reportable Quantities, and Notification Requirements for Hazardous Substances Under CERCLA," Table 302.4, 17 DEC 90, The Bureau of National Affairs, Inc..

the concentration range of some of the other contaminants also exceed the reportable quantity.)

2.2 Determination of Non-hazardousness

In order to determine if the bilge waste is hazardous, the Code of Federal Regulations (CFR) must be consulted. According to the CFR (40 CFR 261), there are five basic questions that must be answered to determine whether or not a waste is a hazardous waste. First, is the waste a solid waste? Second, if the waste is a solid waste, is it excluded from being considered a hazardous waste? Third, if the waste is not excluded, does the waste exhibit the characteristics of Subpart C of 40 CFR 261? Fourth, if the waste does not exhibit the characteristics of Subpart C, is it listed as hazardous waste in Subpart D of 40 CFR 261? Finally, is the waste a mixture of solid waste and a hazardous waste which is listed in Subpart D of 40 CFR 261? For Bilgewater these questions are answered in detail in the following paragraphs.

The first question, whether the waste is a solid waste is essential because "If a material is not considered a solid waste, it cannot by definition be a hazardous waste" (Lindgren 1989, 17). Intuitively, bilge*water* would not seem to be a solid waste. However, "solid waste," as defined by the USEPA, includes materials in the liquid, gaseous, or semi-solid states as well as the solid state. "Solid waste" as defined by 40 CFR 261.2 is any discarded material that is abandoned, recycled, incinerated, or disposed of and is

considered inherently waste-like. It is important to note that although 40 CFR 261.2 excludes certain industrial wastewater discharges from being considered as solid wastes, the CFR specifically adds:

> This exclusion applies only to the actual point source discharge. It does not exclude industrial wastewaters while they are being collected, stored, or treated before discharge, nor does it exclude sludges that are generated by industrial wastewater treatment (Traverse 1991, 346).

Clearly, then bilge waste is a solid waste.

The second question is whether the solid waste is specifically exempted from being considered hazardous. Specific exemptions as found in 40 CFR 261.4(b) are "most household wastes," "most fertilizers," "certain mining overburdens," "most waste ash from coal and fossil fuel burnings," "wastes associated with energy exploration," "certain wastes containing specific forms of chromium," "certain wastes associated with mineral extraction," "cement kiln waste," and "discarded wood or wood products" (Traverse 1991, 347). Since none of these exemptions describe bilge waste, it is not specifically excluded from being a hazardous waste.

The third test is whether or not the waste exhibits any of the characteristics listed in Subpart C of 40 CFR 261. The four characteristics are ignitability, corrosivity, reactivity, and toxicity. Aqueous solid wastes exhibit ignitability, per 40 CFR 261.21, if they have a flash point

less than 140 F. Since bilge wastes have a flash point of 189 F, bilge waste does not exhibit ignitability. Aqueous solid wastes exhibit corrosivity, per 40 CFR 261.22, if their pH is equal or less than 2.0 or equal or greater than 12.5, or corrodes steel (SAE 1020) at a rate greater than 0.25 inches per year at 130 F. Bilge wastes have a pH between 6 and 8, and bilgewater can be found in a steel ship for decades without destroying the ship. Therefore, bilgewater is not considered corrosive. A solid waste exhibits reactivity, per 40 CFR 261.23, if it reacts violently when mixed with water, forms explosive mixtures or toxic vapors when mixed with water or, among other things, is normally unstable at standard temperature and pressure. Bilge waste does not exhibit reactivity, as it is a relatively stable mixture with water that does not spontaneously react.

> A solid waste exhibits the characteristics of EP toxicity if...the extract from a representative sample of the waste contains any of the contaminants listed..(Table 2.2) at a concentration equal to or greater than the respective value given in that table (Traverse 1991, 356).

Table 2.1 lists the contaminants with their concentrations found in bilge waste. By comparison of Tables 2.1 and 2.2 it can be seen that the bilge waste does not exhibit EP (Extraction Procedure) toxicity.

The fourth test, required to determine if a waste is hazardous, is whether or not the waste is specifically

Table 2.2*
Maximum Concentration of Contaminants for Characteristic of EP Toxicity

EPA Hazardous Waste Number	Contaminant	Maximum Concentration (mg/l)
D004	Arsenic	5.0
D005	Barium	100.0
D006	Cadmium	1.0
D007	Chromium	5.0
D008	Lead	5.0
D009	Mercury	0.2
D010	Selenium	1.0
D011	Silver	5.0
D012	Endrin (1,2,3,4,10,10-hexachloro-1, 7-epoxy-1,4,4a,5,6,7,8,8a-octahydro-1, 4-endo, endo-5,8-dimethano-naphthalene)	0.02
D013	Lindane (1,2,3,4,5,6-hez- chlorocyclohexane, gama isomer)	0.4
D014	Methoxychlor (1,1,1-trichloro-2,2-bis [p-methoxy-phenyl]ethane)	10.0
D015	Toxaphene ($C_{10}H_{10}Cl_8$, Technical chlorinated camphene, 67-69 percent chlorine)	0.5
D016	2,4-D (2,4-Dichlorophenoxyacetic acid)	10.0
D017	2,4,4-TP Silvex (2,4,5-Trichlorophenoxy-propionic acid)	1.0

*Traverse, Leo, THE GENERATOR'S GUIDE TO HAZARDOUS MATERIALS/WASTE MANAGEMENT, p. 357, Van Nostrand Reinhold, 1991.

listed as hazardous in Subpart D of 40 CFR 261. Neither "bilgewater" nor "bilge waste" are listed in Subpart D.

The final test, in determining if the waste is hazardous, is whether or not the waste is a mixture of solid waste and hazardous wastes which are listed in Subpart D. Bilge waste is such a mixture. However, such a mixture need not be considered hazardous if "...the mixture no longer exhibits any characteristic of hazardous waste identified in Subpart C" (Traverse 1991, 175). The third test, mentioned above, confirmed that bilge waste did not exhibit any of these characteristics.

Based on the five tests above, bilge waste should be considered as non-hazardous waste, by Federal standards. However, State laws can pre-empt Federal laws. California state law, for instance, specifically lists "bilge waste" as hazardous waste. Since Hawaii's state law does not mention bilgewater or bilge waste, the Navy Complex at Pearl Harbor then relies upon the Federal determination of Hazardous Waste.

2.3 Some Applicable Regulations

Since the bilgewater is very high in both salinity (11,000 mg/l chlorides) and oil/grease content (9,000 mg/l), it is unique in composition as a waste material. No Best Available Technology, or BAT, has been established to-date (1984 USEPA "Treatability Manual") for anything similar to bilgewater.

The Federal Comprehensive Environmental Response, Compensation and Liability Act (CERCLA), defines "hazardous substances" in section 101 (14). The law states, "The term (hazardous substance) does not include petroleum, including crude oil or any fraction thereof which is not otherwise specifically listed..." The Resource Conservation and Recovery Act, required the USEPA to determine if used oil should be considered as hazardous waste. In 1986, according to an engineering report (U.S. Navy, Naval Facilities Engineering Command, Southwest Division, San Diego, CA. 1991), the USEPA decided not to list used oil as a hazardous waste. However, the U.S. Supreme Court, upon citizens' requests, mandated that the USEPA reconsider it's decision. Due to the high concentration of oil and grease in bilge water, it is expected that *if* used oil becomes a hazardous waste, bilge waste will become a hazardous waste. As of February 1992, the USEPA had still not listed used oil as hazardous waste.

The removed oil is recycled, or sold to vendors, as used oil. If used oil becomes classified as a hazardous waste both the oil/water separation and the NSC oil reclamation facility would require a RCRA hazardous waste treatment permit. If not treated on base, the used oil would have to be stored and handled as hazardous waste and sold to a RCRA-permitted hazardous waste facility via an EPA-approved transporter.

CHAPTER 3
BILGE WASTE GENERATION AT PEARL HARBOR

3.1 Method of Calculation

Based on the sum of the days that each ship was in-port, and the type of each ship, daily and monthly bilgewater generation rates (for the year 21 Feb 91 to 21 Feb 92) were compiled. The ship data was obtained from the Navy Public Works Center, Pearl Harbor, "Hotel Services" listing of ships requesting "hotel" (utility) service in-port. The listed ships were divided into 3 classes as indicated in Table 3.1: 1) oil replenishing ships, 2) service craft, or 3) all other surface ships. The data in Table 3.1 was then used to determine the bilge waste generated each day by each ship in each class. Not included are the aircraft carriers, submarines and foreign ships which visit port. Aircraft Carrier visits to Pearl Harbor are rare and are at the remote Hotel docks. Submarines generate much smaller amounts of bilgewater (100 gpd) and are handled differently. Most foreign ships are not in-port long enough to require emptying their bilge tanks. For computational purposes the minimum, average, and maximum flow rates were based on the number of each class of ship in port that day multiplied by the average daily flow rate. Appendix B lists, by day and month the volume of bilgewater generated at the Bravo, Hotel, Kilo, and Mike piers for the one year period. The Sierra (submarine) piers were not

surveyed, since the small volume of bilgewater generated by submarines is relatively not significant.

Table 3.1*
Bilge Waste Generation by Ship Type

Ship Class	Flow Rate (gpd) Q_{avg}	Q_{max}
Aircraft carriers and Oil replenishing ships	50,000	135,000
Service craft	50	1,000
All other surface ships	3,700	14,000
Submarines	100	1,000

*Department of Defense, MILITARY HANDBOOK, Industrial and Oily Wastewater Control, MIL-HDBK-1005/9, (Sep., 88).

3.2 Generation Data for Pearl Harbor

Pearl Harbor is one of the 5 largest U.S. Naval ports in terms of number of ships and personnel, with over 50 ships in port during peak periods. The volume of bilgewater generated depends on a ship's design. Aircraft carriers and auxiliary oilers generate an average of 50,600 gpd of bilgewater, while "surface combatants" generate an average of 3700 gpd of bilgewater.

Appendix B lists the daily and monthly generation rates over a one year period. The annual generation of bilgewater for Pearl Harbor was estimated to be 19.916 million gallons. The percentage of occurrences, where daily-generated volumes of bilge waste are less than a given amount, are plotted against given generation volumes in Figure 3.1. The average daily generation rate for bilgewater at Pearl Harbor is

DAILY BILGE WASTE GENERATED AT PEARL HARBOR

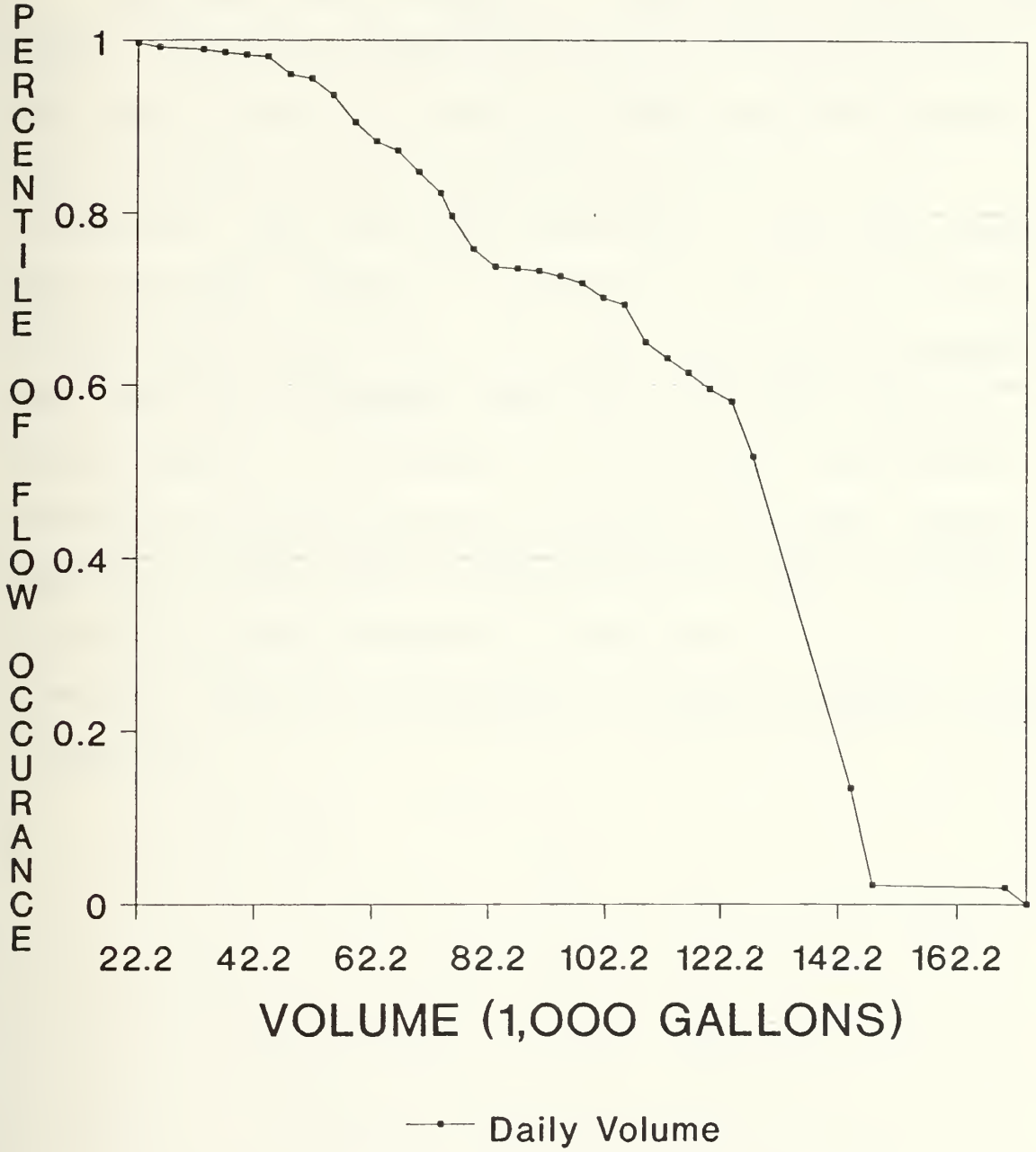


Figure 3.1

Statistical Distribution of Daily Bilge Generation

approx. 51,600 gpd, the maximum generation rate (around Thanksgiving holiday) is approx. 136,800 gpd, and the minimum generation rate is approx. 33,300 gpd. The 95% confidence rate is 112,900 gpd, from Figure 3.1.

The Bravo docks (Figure 3.2) receive by far most of the ships. Although the Bravo piers account for only 58 % of the annual volume of bilgewater, during spring and summer months the Bravo docks generally receive 80 % of the bilgewater. When the oilers are in-port at the Mike Docks, the Mike piers (Figure 3.2) account for over 56% of total generation of bilgewater. The Mike docks annually account for 36% of the bilgewater generated. The Hotel and Kilo docks (Figure 3.3) typically did not receive significant amounts of bilgewater during the spring and summer months last year. These docks accounted for 2.1 and 3.5% of the annual bilgewater generation, respectively. This is of essential concern when designing a collection system for the bilgewater.

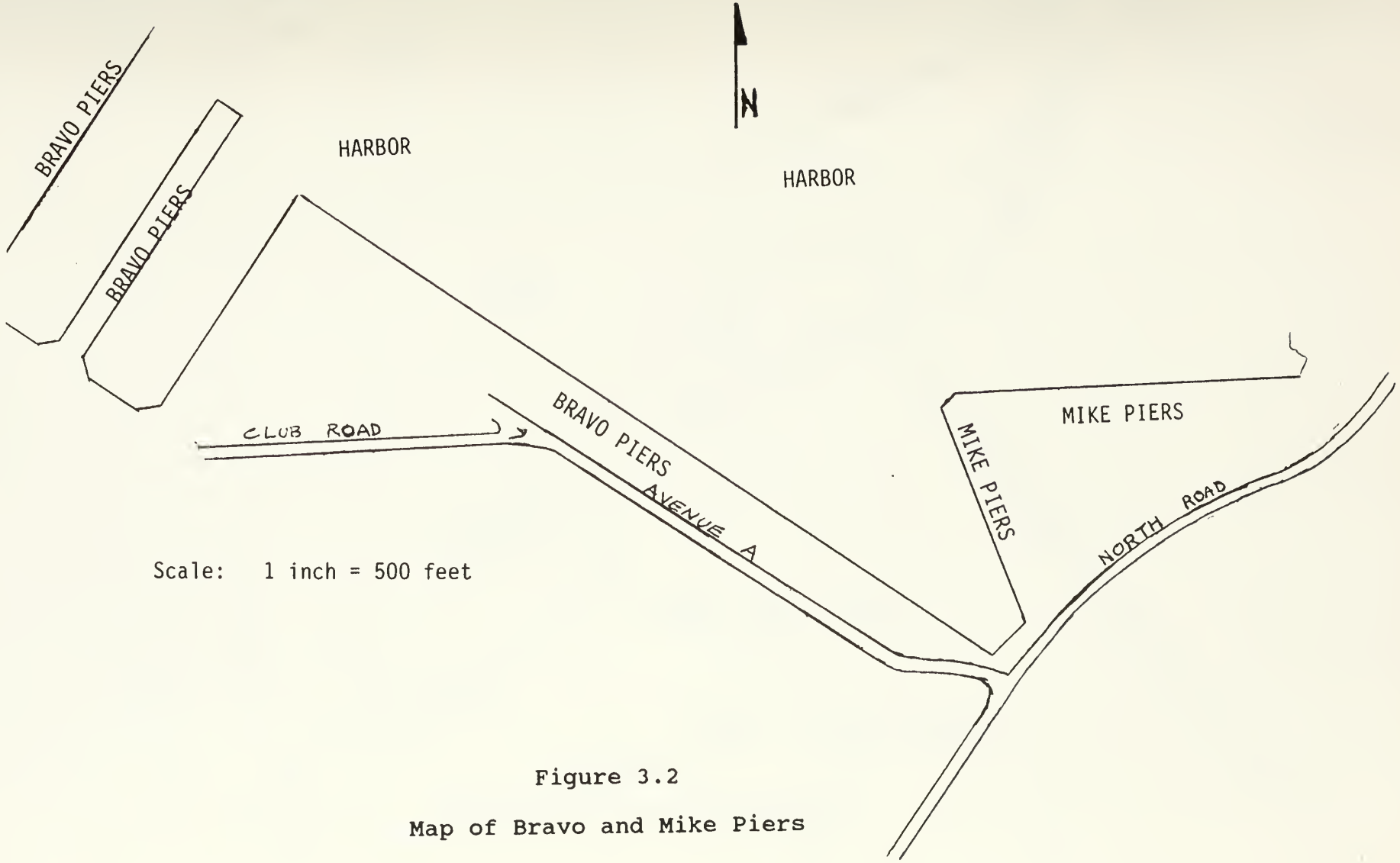
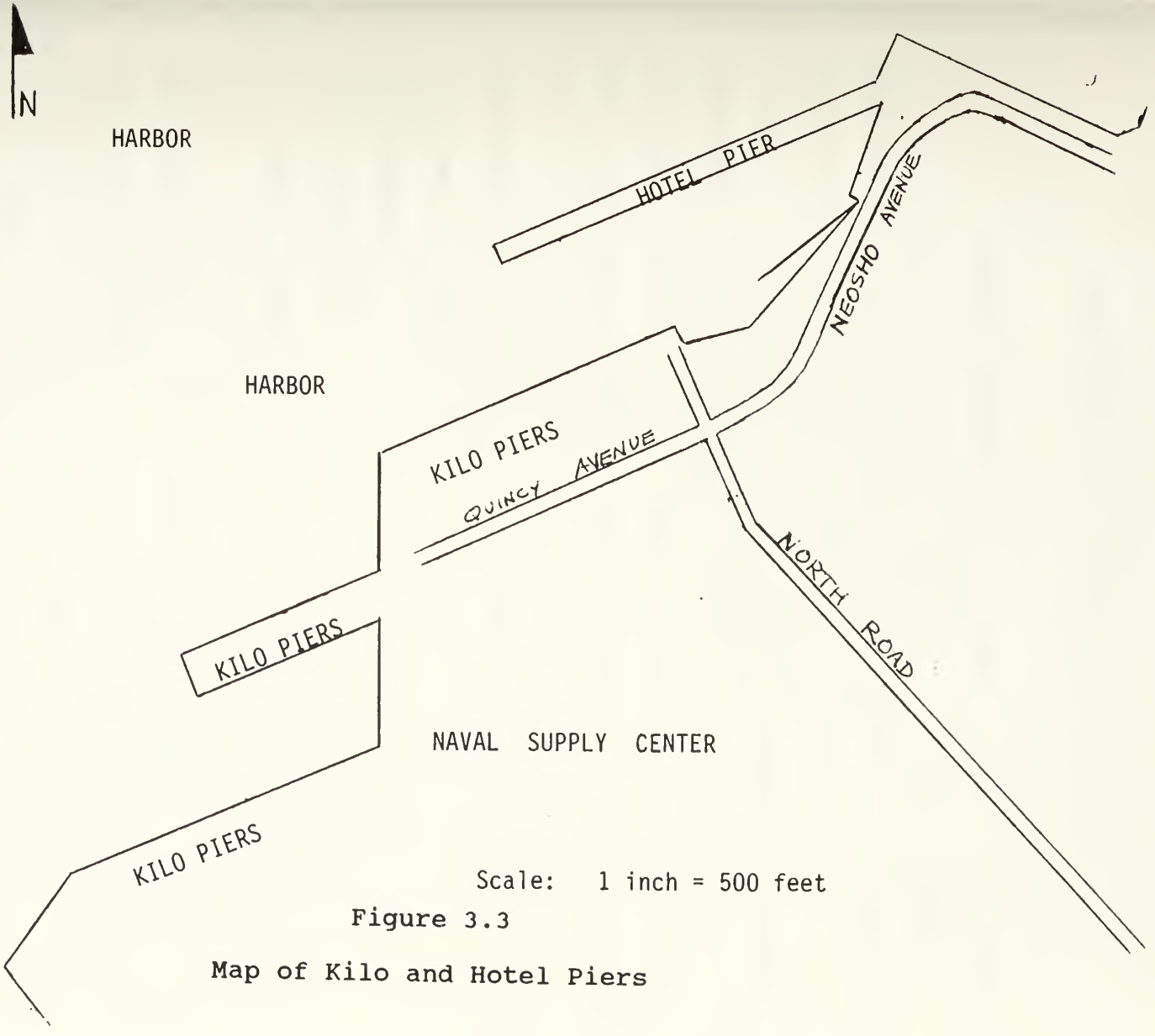


Figure 3.2

Map of Bravo and Mike Piers



Scale: 1 inch = 500 feet

Figure 3.3

Map of Kilo and Hotel Piers

CHAPTER 4
FORMULATION OF ALTERNATIVE SOLUTIONS

4.1 General

The ordinary process flow in water quality management is collection, followed by treatment, and then disposal. However, the goal of water quality management is to restore and maintain the chemical, physical, and biological integrity of the receiving water of a wastewater discharge. Therefore, collection options are dependent upon the treatment method, and the method of treatment is dependent upon the disposal method. Thus, although it seems backwards at first, the best method for evaluating the management options is to follow the order from disposal, through treatment, to collection.

4.2 Disposal

4.2.1 Background

Three disposal options exist for the Navy's bilgewater. First, the bilge waste can be minimally treated and placed into the sanitary sewer system at Pearl Harbor. Second, the waste can be treated extensively for either direct discharge into the marine environment or reuse. Third, a contractor can be hired to dispose of the bilge waste off-base.

4.2.2 Sanitary Sewer Disposal

Wastes discharged into Pearl Harbor's Ft Kamehameha sanitary sewer system (Figure 4.1) must meet certain requirements, termed pretreatment requirements, as listed in Table 4.1. Also listed in Table 4.1 are the various

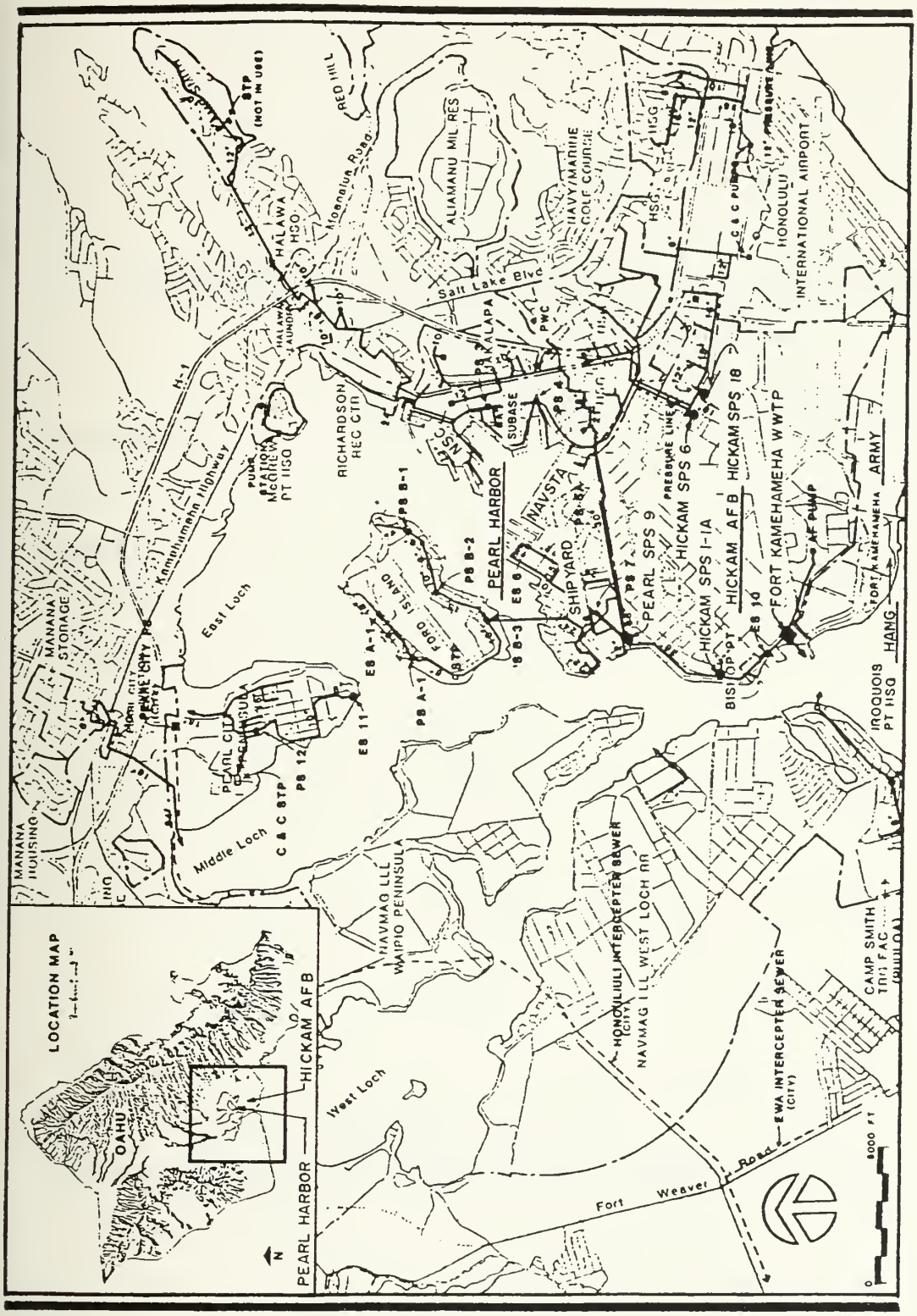


Figure 4.1
Ft Kamehameha Sanitary Sewer System

Table 4.1
Comparison of Average Separated Bilge Wastewater with Pretreatment Requirements for the Pearl Harbor Military Sanitary Sewer System

CONTAMINANT	Pretreatment Requirements* (mg/l)	Average wastewater Contamination** (mg/l)
Beryllium	0.1	< 0.03
Cadmium	0.26	0.04
Chromium	1.71	0.367
Copper	2.07	1.33
Lead	0.43	< 0.44
Mercury	0.01	< 0.01
Nickel	2.38	< 1.60
Silver	0.24	< 0.04
Zinc	1.48	5.08
Solvents	0.5	0.655
Total Toxic Organics	1.37	8.47

*(COMNAVBASEPEARLINST 11345.2C)
**(U.S. Navy, Naval Facilities Engineering Command, Southwest Division, San Diego, CA. 1991)

pollutant concentrations in the separated-bilgewater. Without any pretreatment (other than oil/water separation), the separated-bilgewater meets all sewer discharge limits except four: chloride, zinc, solvents, and total toxic organics (TTO). (Note: Total Toxic Organics (TTO) is the summation of close to 100 tests for organic toxin concentrations. Thus, the TTO value does not represent any one organic but the summation of many different types of toxic organics.) As noted in Table 2.1, 88% to 90% of the total toxic organics is due to the 1,1,1-trichloroethane compound. Therefore, it is the 1,1,1-trichloroethane that makes the bilgewater exceed the pretreatment requirements on the average.

Bilgewater typically contains 11,000 mg/l of chlorides, which greatly exceeds the pretreatment level required for the Ft. Kamehameha sewer system. The solvent limit is a local limit required to maintain the Ft. Kamehameha wastewater treatment processes. The bilgewater solvent concentration only slightly exceeds the average limit (0.15 mg/l above limit). The zinc and TTO limits are EPA standards. The average concentrations of zinc and TTO in bilgewater are more than 3 and 6 times over their respective pretreatment limits. While trace amounts of priority pollutants are found in bilgewater, no classified hazardous substances are found in the bilgewater.

In particular if all ships were outfitted with onboard Oil/Water Separators (OWSs), which is a Navy goal for 1996,

the separated bilgewater (after the oil has been removed) may possibly be pumped directly into the ship's sewage (CHT) tank. This, of course, would require further modification to the ship itself and is beyond the scope of this paper. The dilution would ensure that the bilgewater met the pretreatment requirements for discharge into the Pearl Harbor military complex wastewater collection system. The dilution should be allowed since the bilgewater is not a "waste" until it leaves the ship and since both the ship's sewage tank and bilges are intended to hold "wastewaters."

Disposal capital costs for discharge into a sewer were calculated in 1976 for a similar plant in San Diego, California. The capital costs for the San Diego plant included costs for an effluent pumping system and a 4,000 ft pipeline with a manhole (Hirsch & Koptionak 1976, 88). The pipeline cost was reduced, in this report, by 75% to reflect only the 1,000 ft. distance to the sewer for the Pearl Harbor location. Otherwise, the capital costs were utilized as presented on page 88 of the San Diego study. As a result the modified capital cost was taken to be $314,000.

Annual costs were determined using the disposal fee of $2.91 per 1,000 gallons discharged into the sewer. This fee is charged to all industrial users of the sanitary sewer and is $58,100 annually for the estimated 20 million gallons of bilge waste generated every year. The cost of running the effluent pumping station was added to the annual discharge fee. The operation and maintenance of the pumping station

was taken to be 2% of the initial cost (Hirsch & Koptionak 1976, 90). Two percent equates to $6,280 annually. Thus the total annual cost for the sanitary sewer disposal is $58,100 plus $6,300, or $64,400.

4.2.3 Direct Marine Discharge

Any discharge into a receiving water must first be permitted under National Pollution Discharge Elimination System (NPDES) of the Federal Clean Water Act. The NPDES permit establishes the allowable concentration of pollutants that may be discharged into a receiving water. The established effluent limitations vary between discharge sites and the amount and quality of effluent. *Typical* discharge limitations for marine waters are compared in Table 4.2 against the concentrations of pollutants found in bilgewater.

As evidenced by the difference between Tables 4.1 and 4.2, disposal into marine waters requires the removal of more contaminants from the bilge wastes. However, marine disposal does not require the costly removal of chlorides, since the bilge chloride level (11,000 mg/l) is significantly lower than the receiving water's chloride level (approximately 19,000 mg/l). Direct discharge (after treatment) into receiving waters usually requires daily monitoring to ensure effluent limitations are not exceeded. (Note that the requirements detailed in Table 4.2 are only typical limitations and actual limitations will vary

Table 4.2
Comparison of Average Separated Bilge Waste Characteristics with Typical Marine Discharge Requirements

CONTAMINANT	Marine discharge Requirements* (mg/l)	Average wastewater Contamination** (mg/l)
Beryllium	N/A	< 0.03
Cadmium	0.02	0.04
Chromium	0.05	0.367
Copper	0.2	1.33
Lead	0.05	< 0.44
Mercury	0.001	< 0.01
Nickel	0.1	< 1.60
Silver	0.01	< 0.04
Zinc	0.3	5.08
Solvents	N/A	0.655
Total Toxic Organics	N/A	8.47

*(Dyer, J.C., Vernick, A.S., and Feiler, H.D. 1981, p. 47)
**(Jacobe Engineering Group, Inc. 1991).

depending on characteristics of the bilge waste and the receiving water.)

In 1973, the Sand Island Wastewater Treatment Plant, in Honolulu, Hawaii constructed an outfall at a cost of $1,400 per linear foot, in 1973 (Grace, 1978). Assuming an acceptable outfall location is 4,000 feet off the shore line from the mouth of Pearl Harbor, the required length of outfall would be 25,000 ft. Thus the capital cost would be $35 million. Annual costs are expected to be negligible.

4.2.4 Contractor Disposal

Disposal via a civilian contractor is the least capital intensive option for disposal. The cost of contractor disposal is dependent upon competition, job market, and many other factors. Currently, at Honolulu Harbor, bilge wastes are handled by contractors. Disposal of bilge waste by a contractor costs between $2 and $3 per gallon, depending upon the amount of certain wastes in the bilge.1 This cost includes collection, treatment and disposal. Treatment consists of a granular activated carbon filter to remove solvents and organics, followed by ultrafiltration to remove the oil fraction, and finished by evaporation.2 This would cost approximately $39.8 million (at $2 per gallon) yearly for the anticipated annual disposal of 19.9 million gallons of bilge waste at Pearl Harbor.

1Source: Personnel conversation with Mr. G. Smith of Unitek, Inc. on 02 July 1992. Range of 1992 unit prices, charged by Unitek for collection, treatment, and disposal of bilgewater from commercial ships.
2*Ibid*.

4.2.5 Cost Comparison for Disposal

Sanitary sewage discharge would require, based on 1976 costs from subsection 4.2.2, $314,000 in capital investments. The capital cost was updated to reflect current (1992) costs, using the *Engineering News Record* (*ENR*) construction cost indices for 1976 (index = 2401) and 1992 (index = 4793), as shown below:

($314,000) x (4793/2401) = $626,800

Again, (subsection 4.2.2) the annual costs for sewer disposal were $58,100 plus 2% of the initial investment. Thus, the 1992 annual costs for sanitary disposal are $70,600. The sewer system is anticipated to have at least a 40 year life expectancy. These costs are shown in Figure 4.2.

Marine disposal, from section 4.2.3, is expected to cost $35 million (in 1973 dollars) with negligible annual costs. Using the *ENR* construction cost indices of 1895 for 1973 and 4793 for 1992. the capital cost was updated to reflect a current (1992) capital cost of $88.5 million. A minimum life expectancy for ocean outfalls is 40 years. This cost is also shown in Figure 4.2.

Contractor disposal, as noted in subsection 4.2.4, has negligible capital costs but very high annual costs. The 1992 costs for contractor disposal were noted above to be $39.9 million, annually. This option has an indefinite life

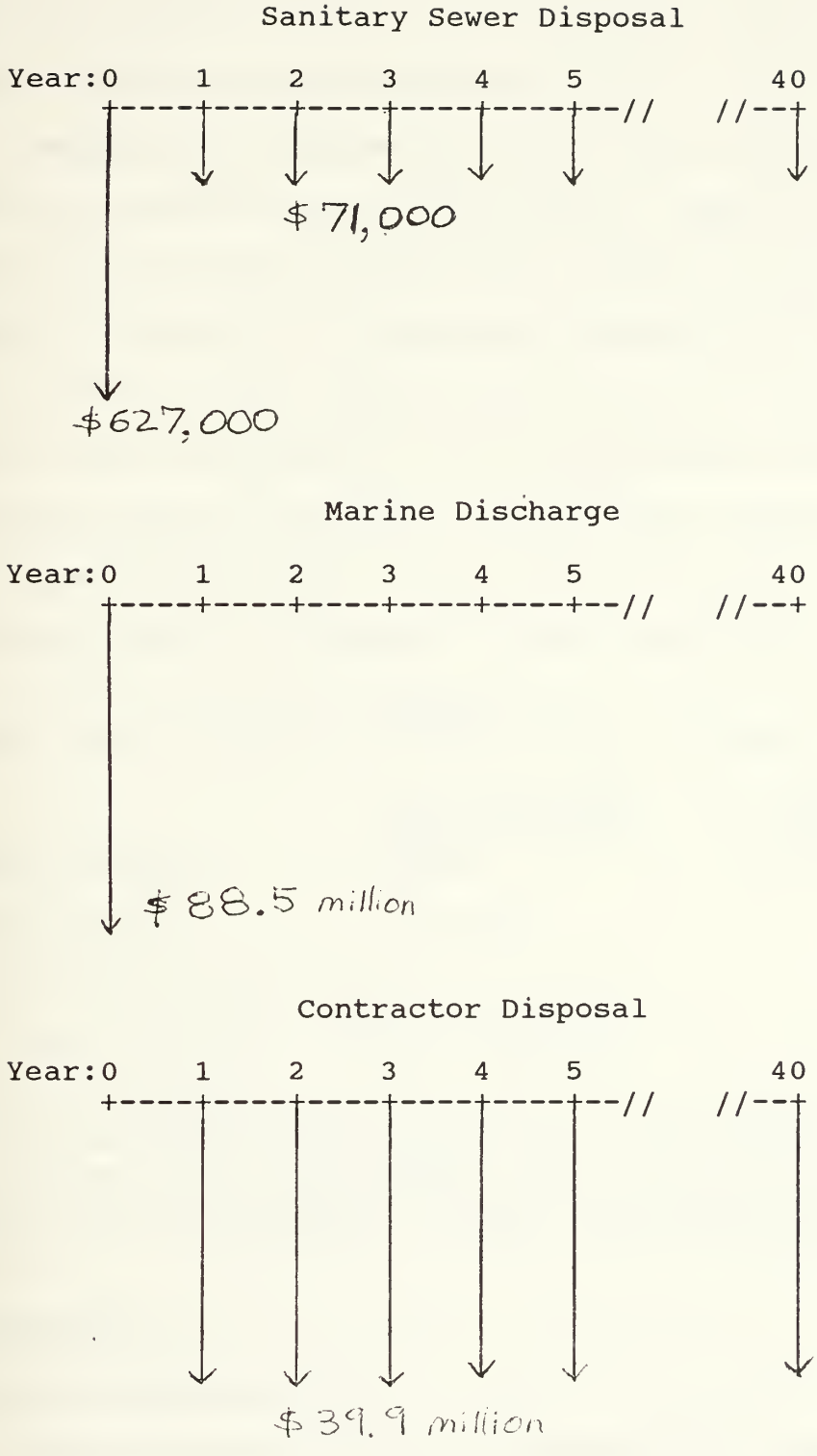


Figure 4.2
Cash Flow Diagrams for Disposal Options

expectancy (assume no less than 40 years). Contractor disposal costs are shown in Figure 4.2.

Comparison of disposal costs were made using the Net Equivalent Uniform Annual Value method. The cost comparison and lead time of each of the three disposal options is detailed in Table 4.3. A discount factor of 10% was chosen, since interest rates ranged from above 10% in the first half of the 1980s and below 10% in the second half. The most economical option is the one with the least negative Net Equivalent Uniform Annual Value. From Table 4.3, the most economical option is disposal via the sanitary sewer.

Table 4.3
Cost and Development Time for Various Disposal Options

Disposal Method	Net Equivalent Uniform Annual Value *	Estimated Min. Time Required to Implement**
Sanitary Sewer	-$135,000	< 2 yr.
Direct Marine Discharge	-$9.1 million	5 yr.
Contractor Disposal	-$39.9 million	< 2 yr.

*Based on current fees for 19.9 million gallons of bilge waste to be disposed of annually, and a 10% discount factor.
**All items with a construction cost of greater than $ 2 million, were considered to require Department of Defense and Congressional approval via the 5 year appropriation cycle.

4.3 Treatment

4.3.1 Treatment Criteria

The *performance* criteria recommended for selecting a pretreatment system for bilgewater are the following:

1. Non-biological: Since the flow of bilgewater varies in volume greatly, is already low in BOD_5, and since no

pretreatment prior this system is anticipated, the fragile biological treatment processes are not recommended. Physical processes are desired.

2. Low operation and maintenance: Generation volumes can be great during certain times of the year and durability, dependability, and ease of repair are essential to ensure proper handling of bilgewater.

3. Capable of maximum flow: A maximum flow rate of 250,000 gpd is anticipated.

4. Capable of large variations in flow: It is probable that one day the system might receive a significant inflow of bilgewater and the next day might not receive any. A minimum flow of 24,000 gpd, an average flow of 55,000 gpd, and a maximum flow of 250,000 gpd, are expected.

4.3.2 Oil/Water Separation

4.3.2.1 General

As mentioned previously bilgewater can contain anywhere from 10 to 5200+ mg/l of oil and grease. This range includes both free and emulsified oil. Although no determination has been published on the actual ratio of emulsified oil to free oil in bilge wastes, the Naval Civil Engineering Laboratory considers bilgewater to "contain *significant* amounts of persistent oil-water emulsions." Oil and grease removal (like municipal wastewater treatment) is done in two steps; primary and secondary treatment. Primary treatment removes the non-emulsified oil from the bilge waste, and secondary treatment removes the emulsified oil.

Oil recovery from waste oil is a mandatory requirement for naval activities. As a result, any treatment of oily waste must attempt to recover the used oil. Oil/water separation (OWS) and oil recovery can be accomplished by several means. The primary means are gravity separation, dissolved air flotation, filtration, coalescence, and distillation.

4.3.2.2 Removal Mechanisms

Gravity separation is, by far, the most common means of separating oil from water (Patterson 1985, 277). Gravity separation utilizes the principle that oil (having a lower specific gravity than water) will float to the top of the water in a settling basin. Oil can then be recovered by skimming the surface of the wastewater. These separation units are referred to as API separators, after the American Petroleum Institute. Efficiencies of 60 - 99% are achievable using a series of gravity separators alone (Patterson 1985, 279). Plain gravity separation is able to remove free oil, however, it is unable to remove the emulsified oil. Costs for a 250,000 gpd capacity gravity OWS in 1980 were $12,700 million for capital investment and $12,300 annually for operation and maintenance (U.S. EPA 1980, IV.3.1-3/4). Due to the inability of API separators to remove emulsified oils, API separators are not recommended.

Coalescence is another form of gravity separation that uses Corrugated or Parallel Inclined plates that intercept the wastewater flow. These units are referred to as Corrugated or Parallel Plate Interceptor (CPI or PPI, respectively) separators. The plates limit the vertical rise of the free oil and as a result the oil builds-up into larger "globules" on the surface of the plates. The large "globules" then settle out as sludge. However, both CPI and PPI units, like the API separators, are also ineffective at significantly removing emulsified oils. Both the CPI and PPI separators require 15 to 20% less space than the API separators (Patterson 1985, 277). The PPI separators are not commonly used.

Costs for a 250,000 gpd capacity coalescing filter system in 1969 were $24,000 for capital investment and $5,417 annually for operation and maintenance (Patterson 1985, 282).

Demulsification agents are chemical additives designed to reduce the amount of emulsified oil in a waste stream. "Most of the physical processes have little effect on stable emulsifications" (Eilbeck and Mattock 1987, 302). Demulsifying agents can greatly increase the efficiency of oil removal, depending upon the amount of emulsified oil present. The three most common chemical processes used in demulsification are "acid cracking," the addition of hydrolysable polyvalent cations, and the addition of polyelectrolytes.

Acid cracking is based on the principle that many oil/water emulsions are not stable at low pH (pH < 2), particularly those caused by soaps and detergents. Adding acid to bilge waste will lower the pH of the waste. The unstable emulsions will then begin to coalesce. Acid cracking produces an acidic effluent that can cause downstream equipment corrosion and which must later be neutralized. As a result, acid cracking is only recommended where acidic wastes are already present. Also, some oil/water emulsions are stable in low pH ranges. Since acidic wastes are not already present and some emulsions may be stable at low pH ranges, acid cracking is not recommended in the treatment of bilge waste.

Hydrolysable polyvalent cations (typically aluminum and ferric salt solutions) can be added to the waste to break the oil/water emulsions. These cations can break emulsions by charge neutralization, by hydrolysis, or by a combination of the two processes (Eilbeck and Mattock 1987, 303). Also, the cations can provide a surface for physical adsorption of emulsions to take place (Eilbeck and Mattock 1987, 302). Thus, due to these many modes of action the addition of hydrolysable polyvalent cations is very effective in breaking emulsions. Another advantage is that precipitation usually takes place under neutral pH conditions. The disadvantage is that the recovered oil is contaminated by the hydrous oxide. Since the Navy recycles the recovered

oil, contamination is unacceptable and therefore the use of hydrolysable polyvalent cations is not recommended.

The third common technique for removing emulsified oil is the addition of polyelectrolytes. Polyelectrolytes (polyamines and polyquaternary salts) cause coagulation by charge neutralization, or flocculation by inter-particle bonding (Eilbeck and Mattock 1987, 307). The main advantage with polyelectrolytes is that only small amounts (a few milligrams per liter) are required for demulsification, and the increase in sludge is negligible.

The effectiveness of over 27 different commercially-available demulsifiers in removing oil from Navy bilge waste was studied by Little and Patterson (1978). Three of the 27 demulsifiers were determined, experimentally, to be "acceptable" for use with Navy bilge waste. The "acceptable" standard was defined in the Little and Patterson study as creating "reasonable separation" within 20 hours at room temperature, and with the water fraction containing less than 200 ppm of oil (Little and Patterson 1978, 587). All three demulsifiers were equally effective non-toxic polyelectrolytes and useful over a pH range of 2 - 10 (Little and Patterson 1978, 588).

The Little and Patterson study also pointed out that, "concentrations of demulsifiers in excess of 0.5% will greatly increase the cost of operations" (Little and Patterson 1978, 588). Minimizing the concentration of demulsifier required can be accomplished by increasing the

temperature of the bilge waste. "For a given concentration of emulsifier or detergent much less demulsifier is required at higher (45 C) than lower (4 C) temperatures (Little and Patterson 1978, 588).

Experimental results from Little and Patterson indicate that 0.3% of one of the three demulsifiers is sufficient to separate the emulsified oils (Little and Patterson 1978, 587). Assuming again an average of 55,000 gpd of bilge waste, 0.3% would equate to 165 gallons of demulsifier daily. The 1976 costs for anionic polyelectrolytes, for demulsification, were $0.75/lb. or $45,170 annually (Hirsch & Koptionak 1976, Supplement, 93). However, a mixing tank is also required to incorporate the demulsifying agents.

Dissolved air flotation is similar in to the gravity OWS with the exception that dissolved air bubbles are emitted from the bottom of the settling tank. The dissolved air bubbles are able to "bring up" to the surface 10-40% of the emulsified oil in addition to 70-95% of the free oil (Patterson 1985, 279) These values apply to dissolved air flotation after primary gravity separation). Costs for a 250,000 gpd capacity air flotation system in 1980 were $1.5 million for capital investment and $150,000 annually for operation and maintenance (U.S. EPA 1980, p. IV.3.4-3/4).

Filtration can be performed only after primary Oil/Water Separation (OWS) due to the nature of the filter media. Media for typical filtration are sand and gravel and for ultrafiltration and reverse osmosis are synthetic

microporous membrane filters. Pretreatment prior to filter application is required to prevent fouling of the filters. Costs for a 250,000 gpd capacity sand and gravel filtration system in 1980 were $500,000 for capital investment and $80,000 annually for operation and maintenance (U.S. EPA 1980, p. IV.3.6-4/5). For ultrafiltration no cost data is available for flows above 30,000 gpd. Therefore estimates were made based on 6 ultrafiltration units at 30,000 gpd are required. The costs for these units are $600,000 each or an assumed total capital investment of $1.2 million; operation costs are $100,000 each or $600,000 annually for all 6 units (U.S. EPA 1980, p. IV.3.7-5/6). Reverse osmosis costs are detailed in the section on zinc removal, which follows. It is important to note that filtration costs are in addition to the primary OWS treatment costs. Filtration methods are limited by fouling problems. Oil and grease will rapidly foul a membrane. In order to minimize fouling, pretreatment is required. Therefore, filtration for oil and water separation is not expected to be useful for bilgewater due to the significant oil content and volumes of bilge wastes generated.

Distillation is a process involving the evaporation of water into steam. The steam rises and separates from the oil which is not vaporized. The oil is not vaporized since the evaporation heating is kept below the oxidation temperature of the oil. The vaporized wastewater is later condensed for further treatment. Costs for a 250,000 gpd

capacity distillation system in 1980 were $2.8 million for capital investment and $750,000 annually for operation and maintenance (U.S. EPA 1980, p. IV.5.11-7/8). Distillation is mechanically complex (fails selection criteria #2), is energy intensive, and relatively very expensive. Distillation is not expected to be a useful option for the treatment of bilge wastes.

4.3.3 Chloride, Solvent, Toxic Organics, and Zinc Removal

4.3.3.1 General

If the discharge is into the sanitary sewer, it is important to note that, excessive chloride content (> 6000 mg/l) adversely affects the biological processes of sewage treatment plants (Sunn, Low, Tom & Hara 1975). The excessive chlorides prove toxic to the microorganisms that "clean" the sewage. Originally, Ft. Kamehameha, the wastewater treatment plant for the Naval and other defense communities at Pearl Harbor, was not designed to receive any shipboard wastes. However, around 1970 the Navy decided to include ship wastewater along with the domestic wastewater treatment at Ft. Kamehameha. An engineering study was commissioned to determine the effects of the shipboard wastewater on the activated sludge process. The study report cited articles on three examples of wastewater treatment in South Florida, where chloride concentrations ranged from 1,500 to 5,000 mg/l (Kennedy Engineers, Inc. 1973). The report also cited a 1965 study where "detectable

changes in sustained performance of activated sludge were not observed below chloride concentrations of 5,000 to 8,000 mg/l...(2,000 to 7,000 mg/l for anaerobic digesters)" (Kennedy Engineers, Inc. 1973). Sharp changes in chloride concentrations, (particularly from higher to lower concentrations), impair or destablize the activated sludge process (Kennedy Engineers, Inc. 1973, 29). As a result of the above studies and conversations, Kennedy Engineering noted that activated sludge processes, such as employed at Ft. Kamehameha, with certain provisions, could handle highly-saline wastewater (Kennedy Engineers, Inc. 1973). The main provisions were that the activated sludge mixed liquor chloride concentration should not exceed 5,000 mg/l and that the incoming wastewater chloride concentration should be equalized (Kennedy Engineers, Inc. 1973).

As noted, bilgewater contains approximately 10,000 to 11,000 mg/l of chlorides due to the heavy concentration of seawater. The chloride content must, therefore, be reduced by at least 50%. Chloride reduction can occur by reverse osmosis, evaporation, ultrafiltration, or by dilution.

"Solvents" and "Total toxic organics" are terms that encompass a wide range of pollutants. However, due to the various solvents, fuels, etc. that find their way into the bilgewater at various levels, it is much easier to deal with these pollutants as two aggregate groups. Typical processes for removing the solvent and total toxic organics (TTO)

groups are steam/air stripping, ultrafiltration, and activated carbon.

Zinc may be removed and/or recovered from wastewater. If recovery is not desired, then removal is usually performed by chemical precipitation. The well-established recovery method is ion exchange. To a lesser extent, reverse osmosis, evaporation, and electrolysis have been used to recover zinc and carbon adsorption has been reported to remove zinc.

4.3.3.2 Removal Mechanisms

In Reverse osmosis wastewater is passed, at very high pressure (typically 600 to 800 psi), through special synthetic membranes. The pore size of these membranes range from 25 to 42 um. Particulates and heavy metals are unable to pass through the membrane, while the high pressure forces the remaining wastewater through. Most desalinization is accomplished by means of reverse osmosis, since reverse osmosis is highly effective at removing chlorides (96.6% removal) from seawater (Nusbaum and Reidinger 1978). Reverse osmosis has not been utilized on a full-scale to remove metals. Lankford and Eckenfelder reported that "reverse osmosis is not a currently (as of 1990) applicable technology (for zinc removal) due to lack of operation data" (1990, 95). It has been reported by the USEPA that reverse osmosis is capable of removing 30 to 77% of TTO (depending on specific type), and 79% of zinc (U.S. EPA 1984, p. III.6.9-1). Costs for a 250,000 gpd capacity ion exchange

system in 1980 were $130,000 for capital investment and $115,000 annually for operation and maintenance (U.S. EPA 1980, p. IV.5.9-4/5).

Evaporation, as the name implies, uses evaporation, induced by elevated temperatures, to separate the wastewater and solids. Evaporation is commonly used in removing salts from seawater. Virtually 100% desalination of water is possible using evaporation. Solids, other than salts and chlorides, are also left behind when the water is evaporated. One such solid is zinc. Only a few full-scale operations have been reported to use evaporation for recovery of zinc. Performance results from these operations were equivalent to chemical precipitation in zinc removal. However, the volume of wastewater leftover to be treated under the evaporative system was much less than under the chemical precipitation system (Patterson 1985, 446). This is beneficial especially in light of the fact that the Ft. Kamehameha sewage treatment plant is already operating at capacity. Evaporation is not effective in reducing solvent and TTO concentrations. Costs for a 250,000 gpd capacity ion exchange system in 1980 were $2.8 million for capital investment and $750,000 annually for operation and maintenance (U.S. EPA 1980, IV.5.11-7/8).

Ultrafiltration has just recently "...advanced to where it can actually be considered for treatment of concentrated low-volume waste streams" (Lankford and Eckenfelder 1990, 95). Therefore only a small amount of performance data on

removal of TTO and solvent removal can be found. Typical removal efficiencies on pilot scale projects range between 50 and 90% removal of TTO and solvents (Lankford and Eckenfelder 1990, 96).

Dilution with non-contaminated/pure water will reduce the concentration of all pollutants in the bilgewater to below required pretreatment levels. If dilution alone (after oil separation) is used, the controlling factor will be the TTO content which would require 6 parts freshwater to every part of bilgewater. If dilution was used after the reduction/removal of other pollutants, 2 parts freshwater to 1 part bilgewater would be required. Due to current water conservation concerns it is unlikely dilution with clean water will be a viable option.

However, use of existing wastewater holding tanks can allow dilution without the addition of potable water. Holding tanks have been, and continue to be, used as a form of dilution to control the amount of chlorides entering the wastewater treatment plant due to the ships' sewage wastewater (as opposed to bilgewater). The sewage from ships is piped to a large 350,000 gallon holding tank prior to entering the Ft. Kamehameha sewage treatment facility (see figure 4.1). The purpose of this tank is to slowly "bleed" the high-chloride wastewater into the sewage treatment plant.

Therefore, one option would be to (after oil separation) route the separated bilgewater into the holding

tank with the ship's sewage wastewater. The chloride content of the wastewater (11,000 mg/l) is equivalent to that of the bilgewater (Kennedy Engineers, Inc. 1977). Ships' generate 2 to 3 times as much sewage as bilgewater, depending on the ship type (Table 4.4). Following oil removal, routing the remaining bilgewater through the holding tank for ships' wastewater may eliminate the need for further pretreatment prior to the FT. Kamehameha wastewater treatment plant.

Steam/air stripping involves the contact of "falling" wastewater with rising steam or air. This contact induces water droplet agitation and eventually the conversion from liquid to air. As the gas transfer rate, which follows Henry's law, increases so does the removal efficiency of the stripping process (Lankford and Eckenfelder 1990, 176). The solvents or TTO are then emitted into the atmosphere with air or steam. Steam/air stripping efficiencies range typically between 75 and 99+% removal of solvent and toxic organics. Costs for a 250,000 gpd capacity ion exchange system in 1980 were $200,000 for capital investment and $1.1 million annually for operation and maintenance (U.S. EPA 1980, p. IV.5.4-3/4).

Activated carbon removes TTO and solvent constituents by sorption. Essentially carbon, that has been heat treated to be "activated," with a low weight to surface area ratio absorbs the pollutants. There are two main types of activated carbon systems, granular and powder. The maximum

Table 4.4
Wastewater and Bilge Waste Generation Comparison per Ship*

Location	Number of Ships	Average Daily Volume Generated (gals.) Wastewater	Bilge Waste	Ratio of Bilge Over Wastewater
Newport	47			
Peak		1,266,900	806,763	0.64
Average		848,087	463,074	0.55
Minimum		438,120	136,008	0.31
Norfolk	94			
Peak		3,206,820	1,902,964	0.59
Average		2,031,450	858,555	0.42
Minimum		971,880	332,885	0.34
Pearl Harbor	72			
Peak		1,481,100	778,867	0.53
Average		613,775	250,169	0.41
Minimum		271,020	51,116	0.19
San Diego	87			
Peak		3,471,180	1,646,646	0.47
Average		2,364,385	860,950	0.36
Minimum		1,270,820	231,260	0.18

*(Bernard Johnson Inc. 1973, 40).

solvent/TTO removal efficiencies have been reported to range from 66 to 99+ %, depending on the specific constituents of the solvents and TTOs (Patterson 1985). Zinc removal efficiencies of > 99 % have been reported using granular activated carbon (U.S. EPA 1980, p. V.A-120). Activated carbon would not be expected to absorb chlorides, since salts are not attracted to the carbon. Costs for a 250,000 gpd capacity activated carbon system in 1980 were $600,000 (granular) and $150,000 (powder) for capital investment and $110,000 (granular) and $100,000 (powder) annually for operation and maintenance (U.S. EPA 1980, pp. IV.5.1-3/4, IV.5.2-3/4).

Chemical precipitation is the most common means of zinc and other heavy metal removal. In order to remove heavy metals (including zinc) by precipitation, a chemical base must be added to raise the pH of the wastewater above 10. The optimum base for zinc, and most heavy metals, is lime, but other bases are also effective. Lime promotes precipitation. The precipitate then settles, forming a sludge at the bottom of the tank. The process train to accomplish this is similar to a flocculator and primary clarifier. Costs for a 250,000 gpd capacity chemical precipitation system in 1980 were $600,000 for capital investment and $190,000 annually for operation and maintenance (U.S. EPA 1980, pp. IV.3.5-12/13).

Ion exchange, simply put, is the process where a medium of stronger chemical affinity forces an "exchange" of ions

with the wastewater pollutant of weaker affinity. For example wastewater containing zinc is passed through the ion exchange media which takes up the zinc and simultaneously gives up sodium in exchange. When the media becomes saturated with cations, the media is cleaned in a regeneration process that includes washing the media with an acid to remove the cations. Different media are available, with resins being the most efficient for metal removal. Costs for a 250,000 gpd capacity ion exchange system in 1980 were $1.19 million for capital investment and $145,000 annually for operation and maintenance (U.S. EPA 1980, pp. IV.5.7-6/7).

Electrolysis has also proved to remove and recover zinc in pilot scale operations. Electrolysis has the benefit of allowing the metal to be directly recovered from the electrode. This process has not gained acceptance in industry to date and thus costs are unavailable (Patterson 1985, 447).

4.3.4 Cost Comparison for Treatment

All costs (both capital and annual) referenced above were updated to reflect current (1992) costs, using the applicable *ENR* indices. The derivation of the updated capital costs is presented in Table 4.5. Annual costs were updated as shown in Table 4.6. Cash flow diagrams for oil/water separators are shown in Figures 4.3 and 4.4. The performance capabilities of the non-oil pollutant removal methods are listed in Table 4.7. Since steam/air stripping,

Table 4.5
Capital Costs for Various Pollutant Removal Mechanisms

Item	Referenced Cost	Applicable ENR Year/Index*	1992 Cost**
API Separation	$ 12,700	1980/3119	$ 19,500
CPI Separation	$ 24,000	1967/1074	$107,100
Air Flotation	$1.5 Mill.	1980/3119	$2.3 Mill.
Demulsify	$167,000	1976/2401	$333,400
Filtration	$500,000	1980/3119	$768,400
Distillation	$2.8 Mill.	1980/3119	$4.3 Mill.
Reverse Osmosis	$130,000	1980/3119	$199,800
Evaporation	$2.8 Mill.	1980/3119	$4.3 Mill.
Ultrafiltration	$1.2 Mill.	1980/3119	$1.8 Mill.
Dilution	Unavailable		
Steam/air Strip	$200,000	1980/3119	$307,300
Activated Carb.	$150,000	1980/3119	$230,500
Chem. Precip.	$600,000	1980/3119	$922,000
Ion Exchange	$1.2 Mill.	1980/3119	$1.8 Mill.
Electrolysis	Unavailable		

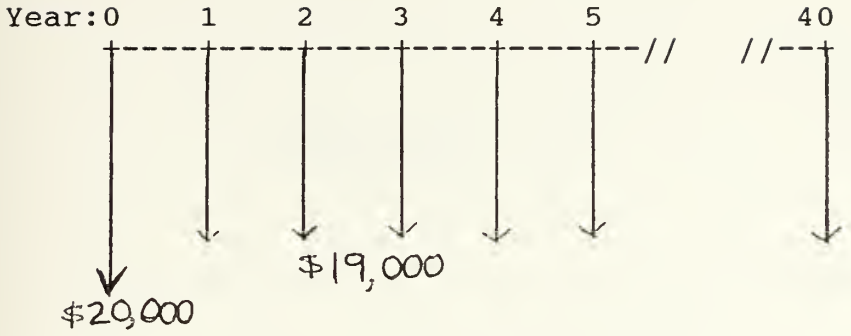
*(*ENR*, 226: 31-51).
**Using the June 1992 index of 4793 (*ENR*, 228: 160).

Table 4.6
Annual Costs for Various Pollutant Removal Mechanisms

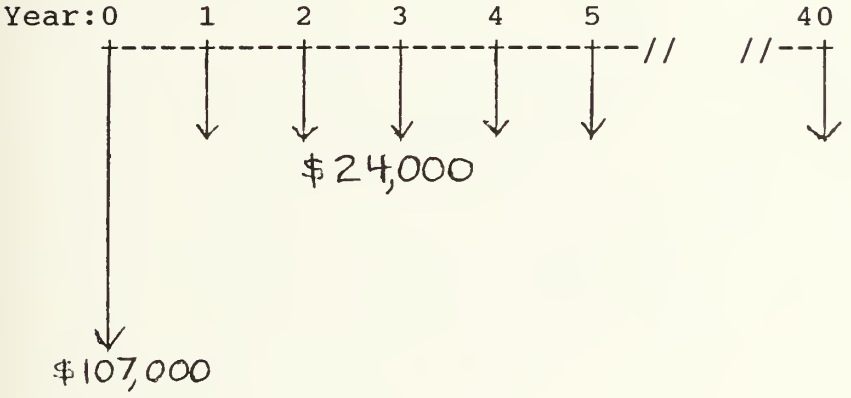
Item	Referenced Cost	Applicable ENR Year/Index*	1992 Cost**
API Separation	$ 12,300	1980/3119	$ 18,900
CPI Separation	$ 5,417	1967/1074	$ 24,200
Air Flotation	$150,000	1980/3119	$230,500
Demulsify	$ 45,170	1978/2776	$ 78,000
Filtration	$ 80,000	1980/3119	$122,900
Distillation	$750,000	1980/3119	$1.2 Mill.
Reverse Osmosis	$115,000	1980/3119	$176,700
Evaporation	$750,000	1980/3119	$1.2 Mill.
Ultrafiltration	$600,000	1980/3119	$922,000
Dilution	Unavailable		
Steam/air Strip	$1.1 Mill.	1980/3119	$1.7 Mill.
Activated Carb.	$100,000	1980/3119	$153,700
Chem. Precip.	$190,000	1980/3119	$292,000
Ion Exchange	$145,000	1980/3119	$222,800
Electrolysis	Unavailable		

*(*ENR*, 226: 31-51).
**Using the June 1992 index of 4793 (*ENR*, 228: 160).

API Separator



CPI Separator



Air Flotation

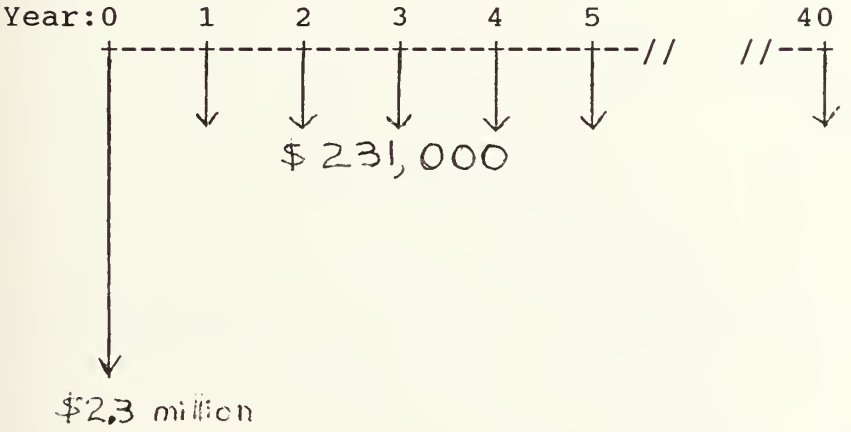


Figure 4.3
Cash Flow Diagrams for Oil Separation Devices

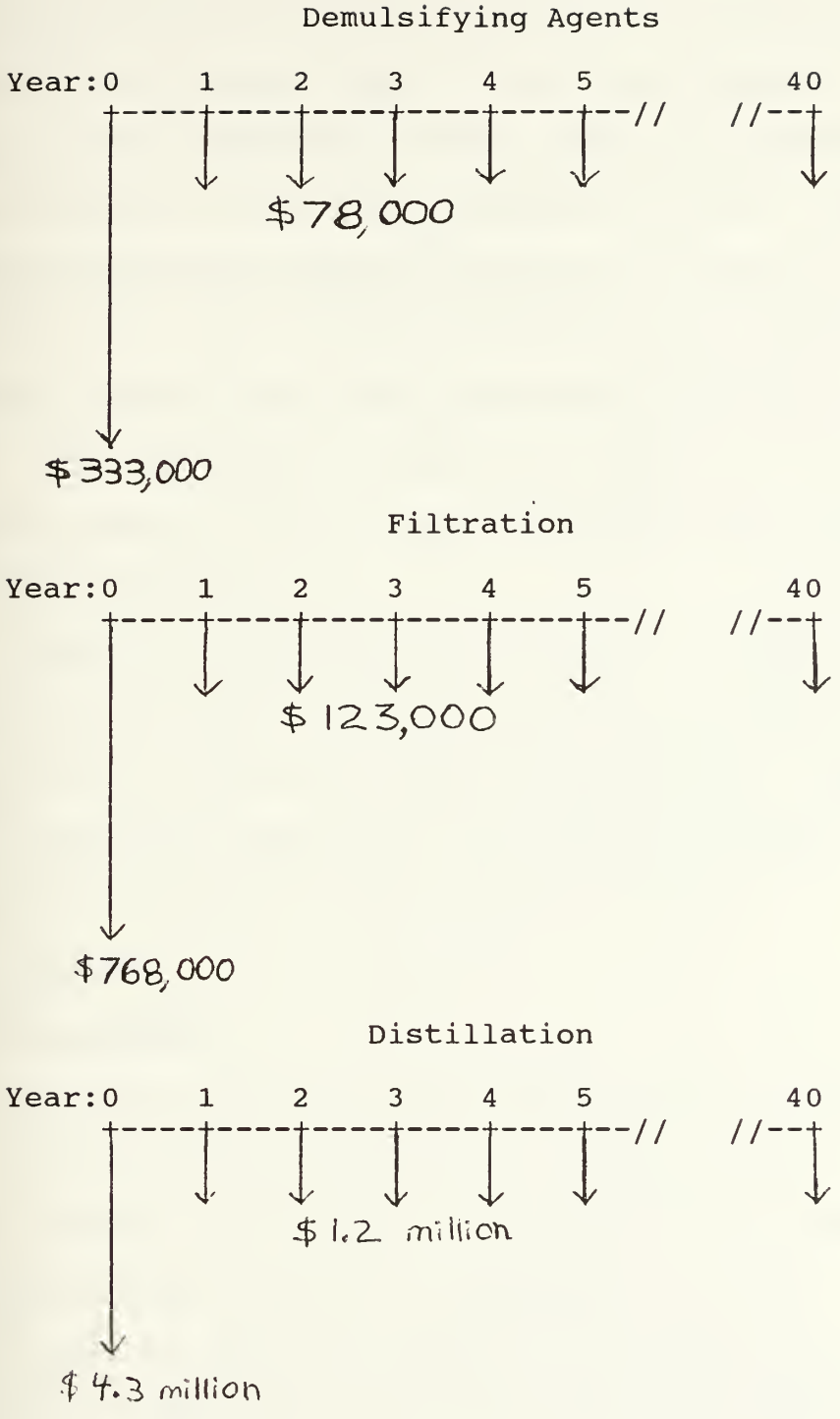


Figure 4.4
Cash Flow Diagrams for Oil Separation Methods

chemical precipitation, ion exchange, and electrolysis are effective at removing only 1 of the 3 pollutants of concern, they were not considered to be an option beyond this point. The remaining devices were considered further. Cash flow diagrams for these remaining devices are shown in Figures 4.5 and 4.6. Due to their different life expectancies, the treatment options were evaluated based on equivalent annual costs. The equivalent values were calculated, assuming an interest rate of 10% for the reasons mentioned earlier, and are shown in Table 4.8.

Therefore, from Table 4.8 the most economical oil/water separator and other pollutant removal methods are the API Separator and activated carbon, respectively. However, since activated carbon does not remove chlorides, reverse osmosis was chosen for the interim solution.

4.4 Collection

4.4.1 Background

Pierside collection and transportation to treatment facilities of bilge wastes can be accomplished by using, 1) a new fixed-piping system, 2) Ship Waste Oil Barges (SWOBs), 3) "pump-trucks," and/or 4) contractor services. The bilge waste would be collected directly from the ships berthed at the Bravo, Hotel, Kilo, and Mike Piers (see Figures 3.2 and 3.3).

The destination or delivery point for the bilge waste is the treatment facility at the Naval Supply Center. The treatment facility should be located at the Naval Supply

Center (NSC), since the oil reclamation facility is already located there. Additionally, at that site are several large (50,000 barrel capacity) above-ground, fuel storage tanks.

Table 4.7
Performance Summary of Various Mechanisms for Removal of Non-Oil Pollutants

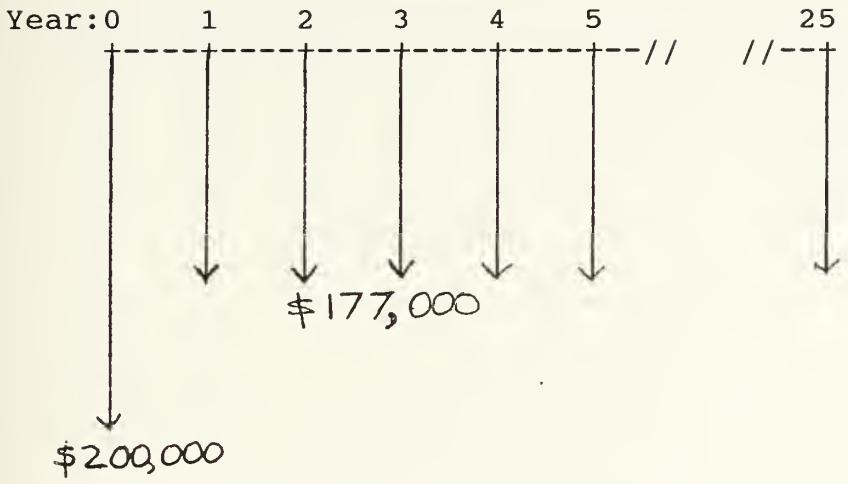
Removal Mechanism	Chloride Removal	Solvent TTO Removal	Zinc Removal
Reverse Osmosis	Yes	some	Yes
Evaporation	Yes	No	Yes
Ultrafiltration	Yes	some	Yes
Dilution	Yes	Yes	Yes
Steam/air Stripping	No	Yes	No
Activated Carbon	No*	Yes	Yes
Chem. Precipitation	No	No	Yes
Ion Exchange	No*	No	Yes
Electrolysis	No	No	Yes

*Removal is possible but not commonly practiced due to impracticality of mechanism for removal of that pollutant.

Table 4.8
Cost of Various Mechanisms for Removal of Pollutants

Removal Mechanism	1992 Equivalent Annual Cost
API Separation	$ 20,900
CPI Separation	$ 35,200
Air Flotation	$465,800
Demulsify	$112,100
Filtration	$201,500
Distillation	$1.64 million
Reverse Osmosis	$198,700
Evaporation	$1.67 million
Ultrafiltration	$1.12 million
Dilution	Unavailable
Steam/air Strip	Not Done
Activated Carb.	$184,000
Chem. Precip.	Not Done
Ion Exchange	Not Done
Electrolysis	Unavailable

Reverse Osmosis



Evaporation

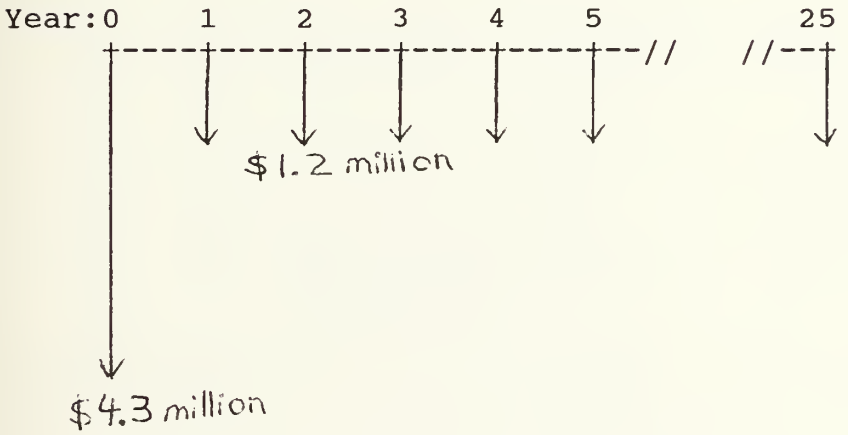
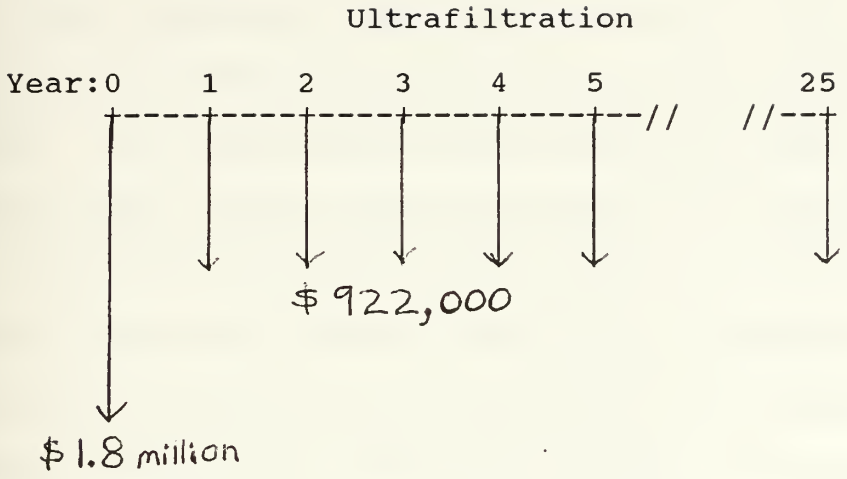


Figure 4.5
Cash Flow Diagrams for Non-Oil Removal Mechanisms



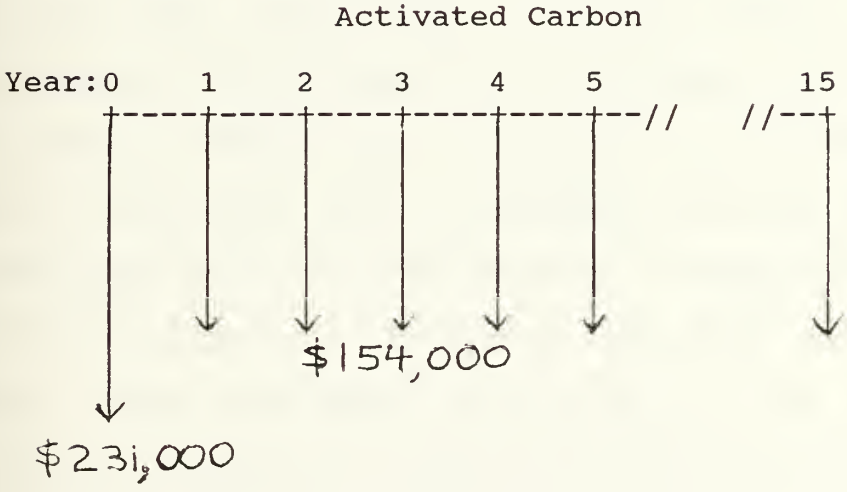


Figure 4.6
Cash Flow Diagrams for Non-Oil Removal Methods

If two are made available, these tanks would be ideal for bilge waste storage. These tanks could act as a reservoir and ensure a uniform flow rate through the treatment process. Two pumps (one for each tank) and approximately a thousand feet of pipe are required for the holding tanks.

Evaluation of the collection options consists of both cost and non-cost factors. Costs to be considered in evaluating the collections options are maintenance, capital outlay, and fee costs. Non-cost factors to be considered are the ability to monitor/test the collected waste, the capacity of collection system, and the time required to put the collection system in-place.

A major concern, aside from cost, is that there must be sufficient time, between collection and treatment of the bilge waste, to allow sampling and analysis of the collected bilge waste. Therefore all collection methods should deliver the bilge waste to two holding tanks to allow time for the waste to be analyzed prior to treatment and disposal Treatment of hazardous waste is not permitted at Pearl Harbor. Prudence requires that portions of the bilge waste be analyzed to ensure no hazardous substances are in the waste.

4.4.2 Fixed Piping

A fixed-piping system requires the greatest outlay of capital, but is the lowest in operating costs of the collection options available. Fixed pipe systems do not allow sufficient time for monitoring.

Table 4.9 displays the discharge rates per ship type. From Table 4.9 three types of ships and two specific ships can discharge bilge wastes at over 100 gpm (again, not considering aircraft carriers). Some of these never visit Pearl Harbor, and those that do make very rare and brief port calls. Therefore a maximum offload capacity of 100 gpm per ship was used to determine the flow rates in pipes. A fixed collection pipe carrying bilge wastes the length of the Bravo Pier would begin with a minimum discharge of bilge waste from 2 ships (200 gpm)3 at one end and end with carrying the bilge waste discharge from 16 ships (1600 gpm). Similarly, at the Mike Piers, a fixed-pipe system would start with collection from 2 ships (200 gpm) and end after collecting bilge wastes from 6 ships (600 gpm). At the union of the Bravo and Mike pier collection systems the combined bilge waste discharged into the pipe would be from 22 ships (2200 gpm). For the Kilo and Hotel piers, the collection pipes would both start by collecting bilge discharged from 1 ship (100 gpm) and both end after

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3Note: Bilge generation rates are based on the maximum number of ships berthed in one day between February 1991 and February 1992, with the following exceptions:

1) Aircraft carriers are rare in Pearl Harbor and are not considered in generation rates.

2) Two oilers in-port simultaneously is also rare, and in the case of the Mike pier maximum bilge generation rate only 1 of the 2 oilers was included in the generation rate.

3) The volume of bilge generated at the Hotel and Kilo piers is relatively small and very erratic, in these cases the 95% confidence generation-rate (vice the maximum) was used.

Table 4.9
Discharge Pumping Rates, per Ship, for Bilge Waste*

MAJOR SURFACE SHIP CLASS[1]	NO. OF PUMPS	CAPACITY EACH PUMP (gpm)
AD	2	100
AE 21	1	50
AE 26	2	50
AF	1	100
AFS	1	50
AG 153	1	50
AO	1	100
AO 177	2	100
AOE	1	100
AOR	1	100
AR	1	100
ARS	2	15
AS	2	100
ASR	2	15
ATF	1	15
ATS	1	15
MSO	2	15
LCC	1	100
LKA	1	50
LPD	2	50
LSD	1	100
LST	2	50
LPH	2	100
CV'S	2	200
CG	2	50
CGN	2	50
DD931-950	2	50
DD 963	2	100
DDG	2	50
FF	1	50
FFG	2	50

[1]Major Surface Ship Classes which will be generating oily waste to be processed ashore. See SECNAVINST 5030.1K, Classification of Naval Ships Craft, [15] for description of other classes.

*(*Military Handbook* 1988, 69).

However, these flow rates assume that all ships are discharging their bilge wastes simultaneously. To account for the fact that the ships will not be discharging simultaneously, a conservative reduction factor of 0.31 was applied to the discharge rates (*Military Handbook* 1988, 71).

The diameter of pipes required for wastewater collection is generally dictated by velocity through the pipe, per Manning's equation. For cast iron pipe (n = 0.013 metric), Manning's equation can be simplified to a nomograph. According to Viessman and Hammer, "Whenever possible velocities of 10 fps or less should be used...(and) ordinarily, minimum velocities are 2 and 3 fps for sanitary sewers and storm drains" (1985, 178). Additionally, oily wastewater collection along piers, should flow between 5 and 7 fps (*Military Handbook* 1988, 71). Using a design velocity of 5 - 7 fps, the above generation rates, and the Manning Nomograph, the diameters for the collection pipes were determined (Appendix D). These are as shown in Table 4.10. For cost comparison purposes, the diameter of pipes used for the entire length of the pier was considered equal in cost to the average diameter from the start to the end of the pier.

The unit costs for the fixed-pipe collection system, including installation are listed in Table 4.11. These costs were obtained from a Navy study to examine various systems to collect ships' waste oil. The 1976 unit prices used in that study were applied to the appropriate unit

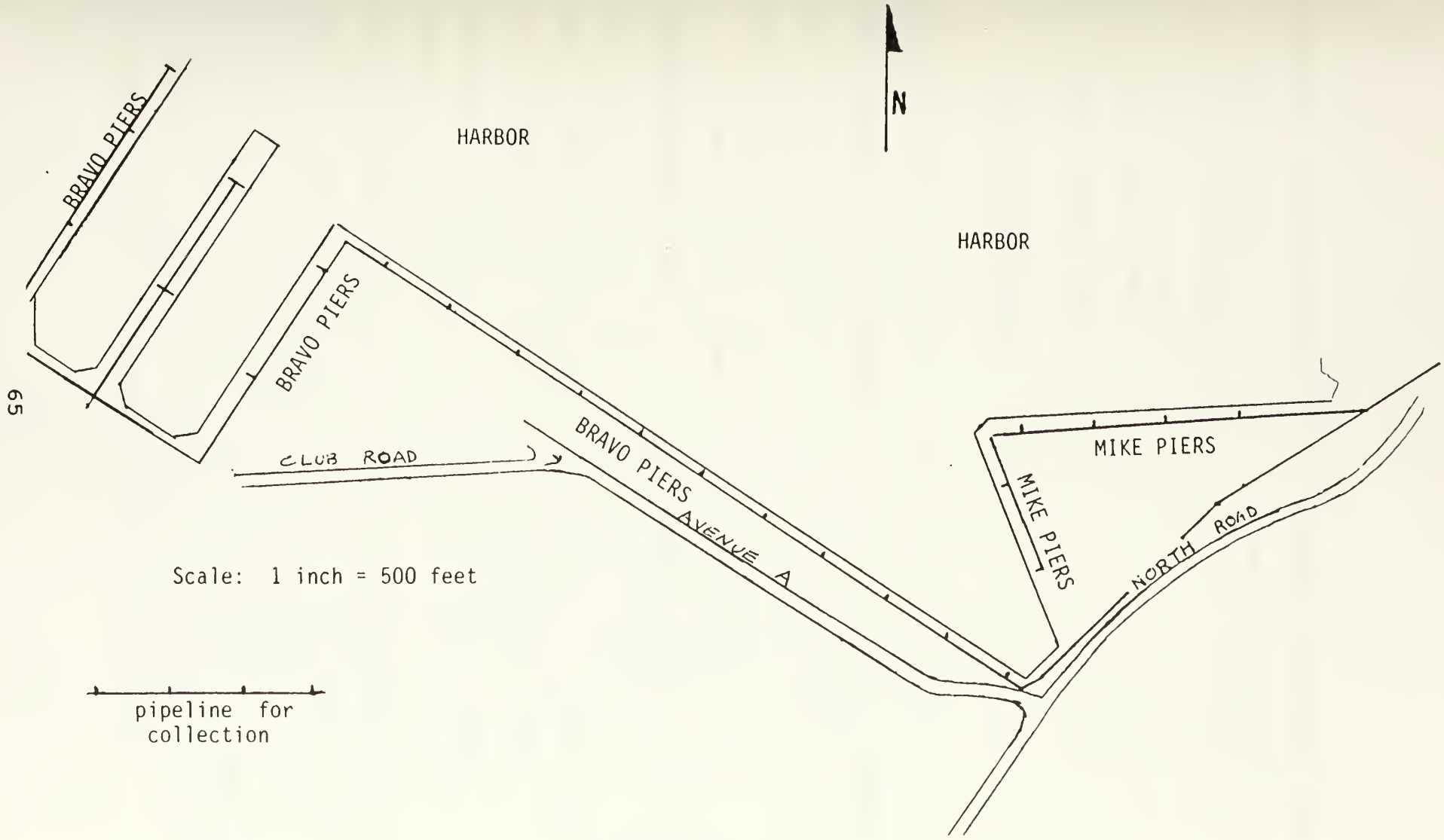


Figure 4.7
Suggested Layout for Fixed Pipe Collection System

Table 4.10
Length and Diameter of Pipes in Fixed-Pipe Collection System

Pipe Location	Diameter of Pipe (in.)
Start of Bravo Piers	3"
End of Bravo Piers	6"
Start of Mike Piers	3"
End of Mike Piers	6"
Start of Kilo Piers	3"
End of Kilo Piers	3"
Start of Hotel Piers	3"
End of Hotel Piers	3"

the fixed piping system to collect the bilge waste at the Kilo and Hotel piers represents over half the total system cost, but collects only 6% of the total bilge waste. This can be seen in Table 4.11.

A fixed piping system would carry the bilge waste immediately from the ship to the treatment facility. This would not allow sufficient time to monitor/analyze the waste, unless the waste was first stored in a holding tank. If a holding tank were used, prior to the first stage of treatment, the waste could be stored just long enough to determine if the waste is hazardous. However, since the inflow of bilge waste is continuous, a second tank would be required to handle the inflow while the other tank is being tested. However, even if both storage tanks had 1 million gallons of storage capacity, only 20 days would be available to sample and complete testing before full storage capacity is reached (based on the average flow of 55,000 gpd).

Table 4.11
Costs for a Fixed-Pipe Collection System

Item	Description	Quantity	Unit	Unit Price*	Cost
1.	Piping along Piers				
	Bravo Pier 18" ACP	6750	LF	$21.00	$141,750
	Mike, Kilo, Hotel piers 10" ACP	4750	LF	$18.00	$85,500
	3" plug & check valves	77	EA	$700.00	$53,900
	4"x3" flange	77	EA	$200.00	$15,400
	2.5" hose coupling	77	EA	$150.00	$11,550
	Concrete valve shelter	77	EA	$750.00	$57,750
2.	Shore Piping				
	Bravo to holding tank				
	18" ACP	4000	LF	$21.00	$84,000
	Excavation	7200	CY	$10.00	$72,000
	Backfill/Compact	7200	CY	$15.00	$108,000
	Pavement Demo/Rpr	4000	CY	$70.00	$280,000
	Hotel pier to holding tank				
	10" ACP	2750	LF	$18.00	$49,500
	Excavation	3713	CY	$10.00	$37,130
	Backfill/Compact	3713	CY	$15.00	$55,700
	Pavement Demo/Rpr	2750	CY	$70.00	$192,500
	Kilo pier to holding tank				
	10" ACP	2500	LF	$18.00	$45,000
	Excavation	3333	CY	$10.00	$33,300
	Backfill/Compact	3333	CY	$15.00	$50,000
	Pavement Demo/Rpr	2500	CY	$70.00	$175,000
3.	Pump Stations				
	Bravo and Mike Piers	13	EA	$92,800	$1,206,400
	Hotel and Kilo Piers	18	EA	$92,800	$1,763,200
				Total =	$4,517,580

(Total without service to Kilo or Hotel Piers = $2,034,350)

4.4.3 Ships' Waste Offload Barges

Ships Waste Offload Barges (SWOBs) can carry up to 75,000 gallons of bilge wastes. Pearl Harbor currently has 4 SWOBs, three of which are currently used to collect clean oil, and one which is dedicated to receive only non-reclaimable oil. SWOB Ships pump directly into the SWOB, which then transports the bilge wastes to the Naval Supply Center. The SWOB contents are then pumped off at the Naval Supply Center, where the oil is reclaimed.

In order to determine the number of SWOBs (75,000 gallon capacity, each) required to replace the donuts, it is necessary to determine the maximum daily volume of bilge waste that the SWOBs can receive from the ships. Indicates in Table 4.12 are the amount of time required for a SWOB to relieve a ship of its bilge waste.

Based on Table 4.12 below, the maximum number a ships a SWOB could unload in one day (1,440 minutes) would be 13 ships. Assuming 3 working shifts, and 1.5 hours off for each shift per day, the number of ships able to be off-loaded would then be 10. The amount of bilge waste generated daily by 10 ships is approximately 37,000 gallons. Therefore a SWOB can handle 37,000 gallons a day under extreme conditions. Using the 95 percentile generation rate of 112,900 gallons (Chapter 3), the number of SWOBs required is four. In order to meet all daily generation amounts recorded in Appendix B, five SWOBs would be required. Five

SWOBs were considered required for comparison purposes against the other collection options.

Currently Pearl Harbor has four SWOBS. However, these SWOBs have duties other than receiving waste oil from bilge

Table 4.12
Amount of Time Required for SWOB Operations

Operation	Time Required*
Disconnect off-load lines	5 minutes
Cast off SWOB	10 min.
Travel (morning) from NSC (1.5 mi. at 4 knots)	25 min.
Travel (night) to NSC	25 min.
Moor to off-load pier	10 min.
Connect off-load lines	5 min.
Off-load oily waste (2 pumps at 160 gpm)	235 min.
Total Required Mobilize/Demobilize Time =	315 min.
Moor SWOB to ship	10 minutes
Connect Ship off-load lines	5 min.
Load SWOB (at 100 gpm)	40 min.
Disconnect Ship off-load lines	5 min.
Cast off SWOB	10 min.
Travel time to next ship (at 4 knots)	15 min.
Total Time Required to off-load each ship =	85 min.

*Times were taken from Hirsch & Koptionak, Consulting Engineers, 1976.

water. Additionally, this may create a problem in that only the same number of ships, as available SWOBs, may offload their bilge wastes at any one time. Therefore, under this collection system, four *additional* SWOBs should be purchased for efficient service to ships and to allow for a back-up should a SWOB be out of operation.

Purchase and maintenance costs for another SWOB, in 1976, were determined to be $478,000 each to purchase and $24,400 annually for operation and maintenance (Hirsch &

Koptionak 1976, 57). However, as the SWOBs are not self-propelled, a tugboat would be required full-time to keep the SWOBs moving. The 1976 costs for tugboats were estimated to be $1.5 million to purchase and $319,000 annually for operation and maintenance (Hirsch & Koptionak 1976, 57). The total cost of a five-SWOB collection system, including SWOBs and tugboat, is $3.89 million (in new purchases) and $417,000 annually (for operation and maintenance).

Current procedures for SWOBs include sampling and sealing the SWOB when it is full. The samples are tested to determine if the oil is reclaimable. After the test is complete, the SWOB is emptied. Contents of the SWOB are disposed of based on sampling test results. This same procedure could be used to determine if the waste is hazardous. However, with only three SWOBs collecting bilge waste at an average of 55,000 gpd, less than three days would be available to sample and complete testing of the bilge waste prior to reaching the storage capacity of the three SWOBS.

4.4.4 Pump Trucks

The use of pump trucks for collection of bilge wastes is common practice in Honolulu Harbor. Each truck typically has a 15,000 gallon capacity. The time required for each pump truck operation is shown in Table 4.13.

Based on Table 4.13, a pump truck working 15 hrs a day can collect and transport 30,000 gallons. Therefore, in order to meet the 95th percentile demand (112,900 gallons),

at least 4 trucks would be required. In order to satisfy all the daily collection requirements noted in Appendix B, a total of 6 pump trucks are required. Six pump trucks would allow the average demand (55,000 gpd) to be collected and transported within an eight hour day.

Table 4.13
Required Time for Pump Truck Operations

Operation	Time Required
Connect off-load line	10 min.
Off-load bilge waste (at 100 gpm)	40 min.
Disconnect off-load lines	10 min.
Travel to next ship.	5 min.
Repeat above for three more ships	190 min.
Travel to NSC (2 mi. at 25 MPH)	5 min.
Connect off-load line	10 min.
Off-load bilge waste (at 100 gpm)	150 min.
Disconnect off-load lines	10 min.
Travel to ship	5 min.
	==========
Time Required to Fill and Empty Pump Truck =	435 min.

The 1976 costs per pump truck were $60,000 to purchase, $0.53 per mile for maintenance, and $23,300 for operation (assuming 20 miles a day per truck, the annual maintenance cost in 1976 would have been $3,869 per truck) (Hirsch & Koptionak 1976, 50). Thus for four trucks, the total capital cost in 1976 would have been $240,000 and the total annual cost would have been $27,000, per truck. Sampling and analysis of bilge waste collected using pump trucks would have to be conducted in the same manner as detailed above in the fixed piping system. Life expectancy of each truck is 8 years.

4.4.5 Contractor Service

A contract with a vendor for another option for collection and transportation of bilge waste. Contractors will employ pump trucks to collect and transport the bilge wastes. Therefore, the contractor's requirements will be the same as established in the previous paragraph.

Contractor service costs to pump and transport wastes, were based on the aforementioned contractor disposal costs. However, since treatment is included in the $2 per gallon price, the price was reduced, conservatively, to $1 gal for just collection and transportation within the Navy complex.

Sampling for hazardous waste would occur as detailed above in the fixed piping system.

4.4.6 Cost Comparison for Collection

A fixed-pipe collection system would cost 50+% more to collect bilge waste at the Kilo and Hotel piers, which only represents 6% of the total bilge waste generated in Pearl Harbor. Thus extending a fixed-pipe system to the Kilo and Hotel piers is not warranted. Fixed-pipe collection costs, from Table 4.8 of Subsection 4.4.2, in 1976 were $2.034 million (excluding service to the Kilo and Hotel piers) in capital investments, with 2% operation and maintenance costs. The capital cost was updated to reflect current (1992) costs, using the *Engineering News Record* (*ENR*) construction cost indices for 1976 (index = 2401) and 1992 (index = 4793), as shown below:

($2.034 mill.) x (4793/2401) = $4.06 million

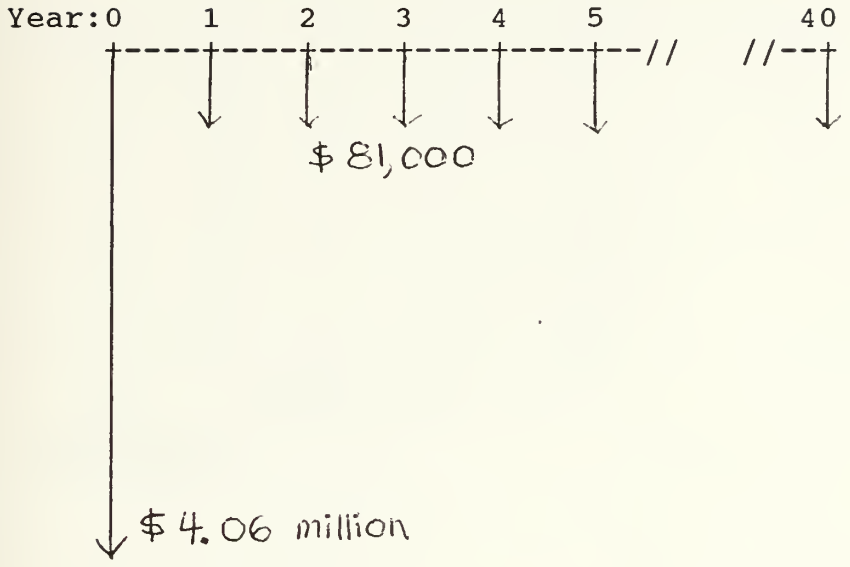
Again, (Subsection 4.4.2) the annual costs were 2% of the initial investment. Thus, the 1992 annual costs for fixed-pipe collection are $81,200. The pipes are anticipated to have at least a 40 year life expectancy. These costs are shown in Figure 4.8.

SWOB collection, from Subsection 4.4.3, is expected to cost $3.41 million (in 1976 dollars) with annual costs of $417,000. Using the *ENR* construction cost indices of 2401 for 1976 and 4793 for 1992, the capital cost was updated to reflect a current (1992) capital cost of $6.81 million and annual costs of $832,400. A minimum life expectancy for ocean outfalls is 40 years. This cost is also shown in Figure 4.8.

Pump truck collection, from Subsection 4.4.4, is expected to cost $240,000 (in 1976 dollars) with annual costs of $216,000. Using the *ENR* construction cost indices of 2401 for 1976 and 4973 for 1992, the capital cost was updated to reflect a current (1992) capital cost of $479,100 and annual costs of $431,200. Each truck would have a standard life expectancy of 8 years. This cost is shown in Figure 4.9.

Contractor collection and transportation, as noted in subsection 4.4.5, has negligible capital costs but very high annual costs. The 1992 costs for contractor disposal were noted above to be $19.9 million, annually. This option has

Fixed Pipe Collection System



SWOB Collection System

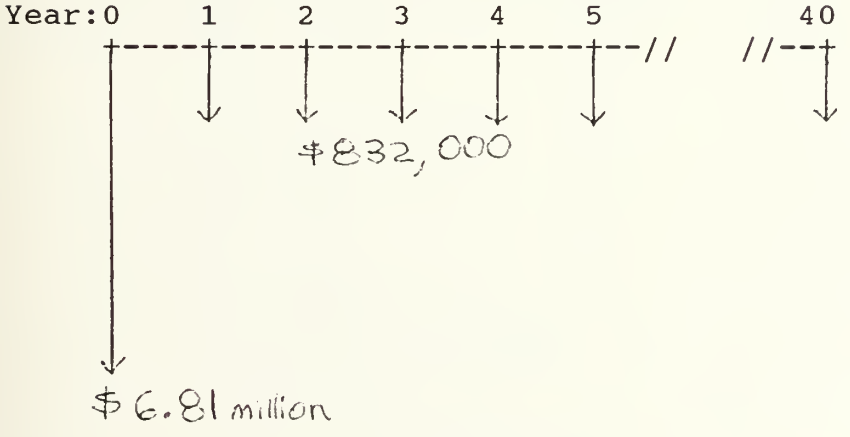
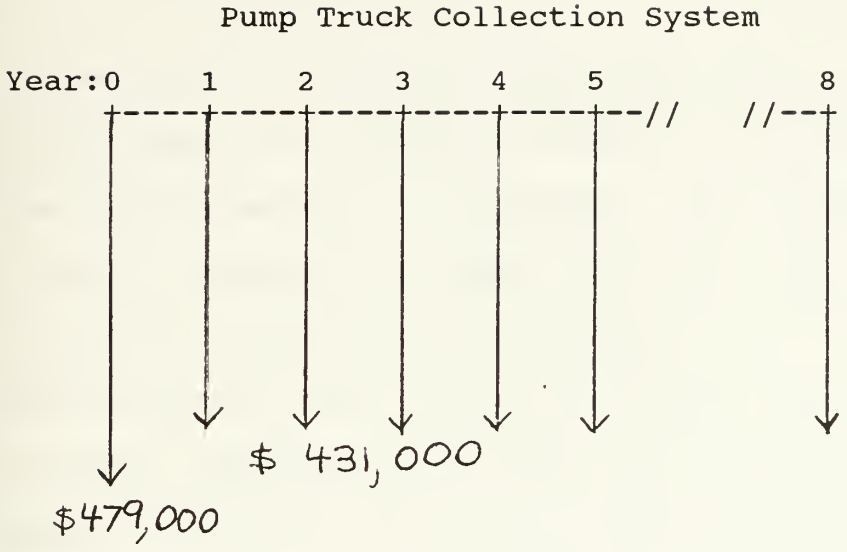


Figure 4.8
Cash Flow Diagrams for Collection Options



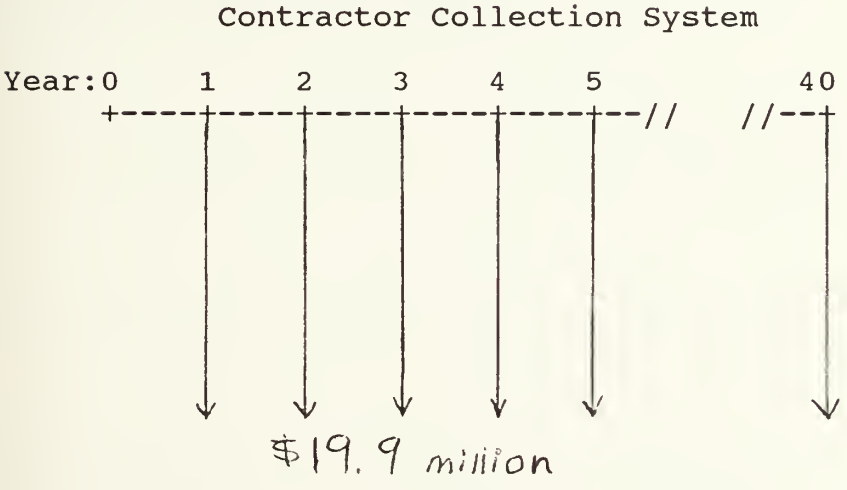


Figure 4.9
Cash Flow Diagrams for Collection Options

an indefinite life expectancy (assume no less than 40 years). Contractor disposal costs are also shown in Figure 4.9.

Comparison of collection costs were made using the Net Equivalent Annual Value method, since not all options had the same life expectancy. The options were compared on an annual basis, assuming 10% annual interest. The equivalent uniform annual costs are shown in Table 4.14. The most economical option is the one with the least negative Net Annual Value. Therefore, from Table 4.14, the most economical option for collection is a fixed-pipe collection system. The Net Annual cost for the Pump Truck method was very close, in economic value, to the fixed-pipe method. However, only SWOBs and pump trucks are immediately available for an interim solution.

Table 4.14
Cost and Development Time for Various Collection Options

Collection Method	Net Equivalent Uniform Annual Value *	Estimated Min. Time Required to Implement**
Fixed-Pipe	-$496,500	5 yr.
SWOBs	-$1.53 million	< 2 yr.
Pump Trucks	-$521,000	< 2 yr.
Contractor Service	-$19.9 million	< 2 yr.

*Based on current fees for 19.9 million gallons of bilge waste to be disposed of annually. Annual costs include capital costs spread across life of method at 10%.
**All items with a construction cost of greater than $ 2 million, were considered to require Department of Defense and Congressional approval via the 5 year appropriation cycle.

CHAPTER 5
RECOMMENDED INTERIM SOLUTION AND EVALUATION

5.1 General Recommendations

As mentioned in the section "Disposal Options," the options available are disposal into the sanitary sewer, direct discharge and contractor disposal. Chapter 4 showed that, of all the disposal options, only disposal via the sanitary sewer was both immediately available (for an interim solution) and cost effective. Therefore, this section will concentrate on disposal into the sanitary sewer. The bilge waste must be treated, however, to meet the pretreatment requirements for the Ft. Kamehameha Wastewater Treatment Plant.

As indicated in Table 4.1, the treatment must reduce the oil/grease, solvent, TTO, chloride, and zinc concentrations. Thus, generally-speaking the treatment "train" should include an oil/water separator followed by a removal of solvent and toxic organics, chlorides, and zinc.

The first step is to separate the oil from the bilgewater with a gravity coalescing separator. Holding tanks should be used to level the bilge waste load on the system. These tanks already exist and are available for this program. Oil/water separation will require a new oil/water separator since the NSC oil/water separator (OWS) has a capacity of only 60,000 gpd. NSC receives the separated oil for reclamation, therefore the location of the

OWS should be at NSC to minimize the handling of the separated oil.

In terms of versatility, availability, and economics of the various mechanisms, the best mechanism for removal of chlorides, zinc, solvents, and some TTO is reverse osmosis. As mentioned earlier, the Navy and Marine Corps have extensive training experience with reverse osmosis units in producing potable water for troops in the field. Additionally, several of these units are already in the Navy's possession (being held for contingency).

The collection options most immediately available (upon discontinuation of "donut" use) for the interim solution are pump trucks, Ship Waste Oil Barges (SWOBs), and contractor collection. These options all require some lead time, and it is anticipated that none of these solutions in itself can handle the entire volume of bilge waste generated. Thus a combination of all three will be required, in the interim to meet demands (fixed piping system should be pursued during this period as a permanent solution.).

5.2 Bench Scale Analysis of Interim Solution

5.2.1 Background

An experiment was run to determine the efficiency of processing the bilge waste through a reverse osmosis filter. The process train used in the experiment is shown in Figure 5.1. Experimental procedures are given in Appendix C. The

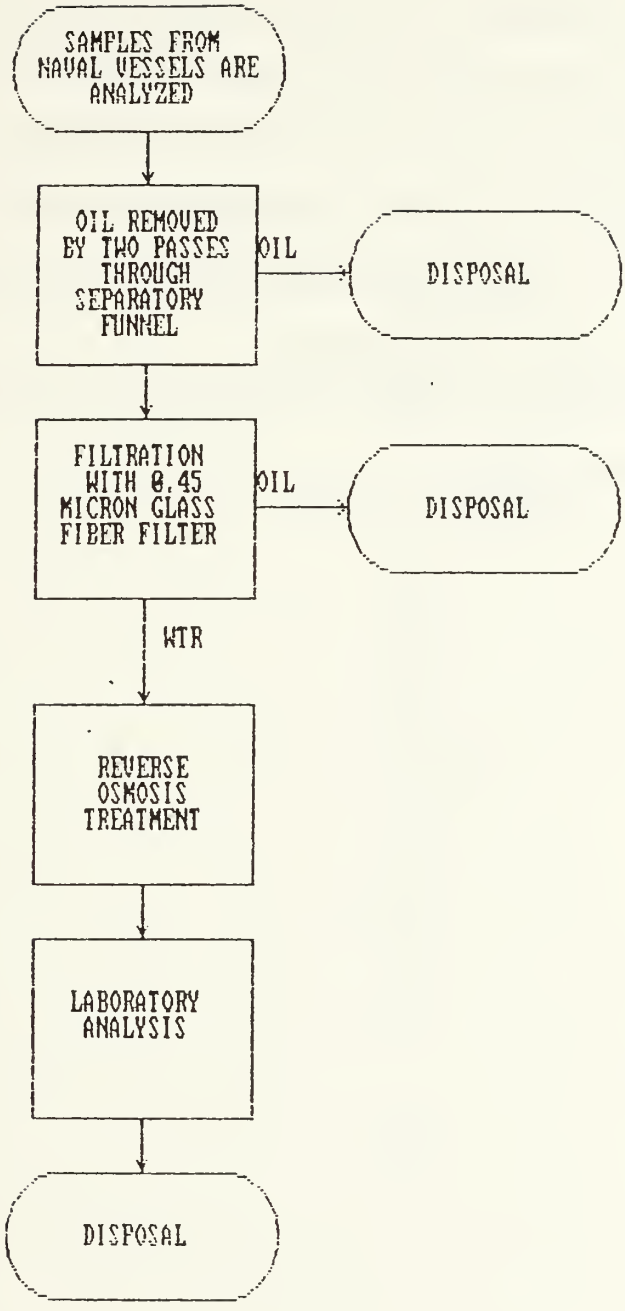


Figure 5.1

Process Flow Sheet for Bench Scale Experiment

extremely small diameter of the pores in the membrane prohibit the passage of virtually all known contaminants.

The primary objective was to determine the effective removal of chlorides from the bilge waste using the reverse osmosis. Secondary objectives were to determine the removal of other contaminants (zinc, solvents, etc.).

5.2.2 Results of Bench Scale Experiment

Table 5.1
Water Quality of Gas Turbine Ship's (Sample GT) Bilge Waste Prior to and After Treatment by Reverse Osmosis

Pollutant	Concentration (ppm) Before Treatment	After Treatment
pH	7	7
Arsenic	<0.1	<0.1
Barium	2	<1
Beryllium	<0.1	<0.1
Cadmium	<0.1	<0.1
Chromium	0.2	0.1
Copper	2.5	0.6
Mercury	<0.005	<0.005
Manganese	0.4	0.2
Nickel	1.0	0.7
Lead	0.4	0.3
Selenium	<0.1	<0.1
Silver	0.1	<0.1
Thallium	0.2	0.3
Tin	<2	<2
Zinc	3	0.8
Cyanide	<0.1	<0.1
Sulfide	<0.5	<0.5
TOC	44	13

Table 5.2
Water Quality of Steam Boiler Ship's (Sample SB) Bilge Waste Prior to and After Treatment by Reverse Osmosis

Pollutant	Concentration (mg/l) Before Treatment	After Treatment
pH	7	7
Arsenic	<0.1	<0.1
Barium	1	<1
Beryllium	<0.1	<0.1
Cadmium	<0.1	<0.1
Chromium	0.1	<0.1
Copper	0.7	0.5
Mercury	<0.005	<0.005
Manganese	0.1	0.1
Nickel	0.5	0.4
Lead	0.3	0.3
Selenium	<0.1	<0.1
Silver	<0.1	<0.1
Thallium	0.2	0.3
Tin	<2	<2
Zinc	2	0.7
Cyanide	<0.1	<0.1
Sulfide	<0.5	<0.5
TOC	48	12,600

Table 5.3
Chloride Reduction with Reverse Osmosis Unit

Chloride Concentrations			
Sample GT		Sample SB	
Influent (mg/l)	Effluent (mg/l)	Influent (mg/l)	Effluent (mg/l)
11,030	4,200*	9,690	5,840
10,470	6,125	9,590	6,810
10,735	5,375	9,400	6,725
8,390*	5,505		6,230
	5,780		6,400
	5,940		4,875*
Avg.	Avg.	Avg.	Avg.
10,745	5,745	9,560	6,401

*Extreme Values Not Included in Calculation of Average.

5.2.3 Evaluation of Bench Scale Results

As mentioned in the "Characterization" section, the level of oil and grease in bilgewater varies dramatically (10 - 5400 mg/l) depending on a ship's operations and the conditions of its equipment. This was confirmed by a visual inspection of the two bilge samples. The lighter colored sample from the gas turbine ship had a heavy yellow oil/grease residue on its surface which left a residue on any lab equipment that it came in contact with. The much darker colored sample from the steam boiler-driven ship had some floating oil residue, but not nearly as much as the gas turbine-driven ship.

Oil residues were separated before the initial analysis and further treatment of the bilge waste. The results of the initial analysis are detailed in Tables 5.1 through 5.3. After separating the oil, the sample from the steam driven ship was still much darker than that from the gas turbine ship. This suggests that the strong difference in color is *not* attributable to the free oil content.

Suspended solids were then removed from the samples to prevent fouling of the reverse osmosis membrane (The suspended solids concentration in the two samples are noted in Table C.1.). After the removal of the suspended solids, there was no longer a sharp color difference between the two samples, as both samples looked very clear and colorless. Observation of the paper filters, after filtration, showed that the total suspended solids removed from the GT sample

were yellowish in color, while the total suspended solids removed from the SB sample were dark-gray in color. Therefore in this case, the sharp color difference appears to be due to the suspended solids. Both samples displayed a similar concentration of total suspended solids.

Reverse Osmosis was the final treatment step utilized in this experiment. The chloride reduction achieved after the bilge waste was passed through the reverse osmosis unit is shown in Table 5.3. The chloride removal efficiency of the reverse osmosis unit was less than anticipated. There is a probable explanation for the less-than-anticipated efficiency. The reverse osmosis filter was a "tapwater" unit (i.e., the filter was intended to be used on tap water in a typical home). This means that the filter only operates at low pressures (> 125 psi) and is efficient (removes > 90% salts) at low levels (< 2,000 mg/l) of chlorides. However, a removal efficiency of approximately only 50% was sought. This experiment used the tapwater element to determine if a 50% reduction could be achieved at the reduced pressure associated with the tapwater element. Since the bilge waste has a chloride level of approximately 10,000 mg/l, it is possible the filter was overwhelmed.

Three steps could be incorporated to improve the efficiency of the reverse osmosis process. First, "seawater" reverse osmosis filters are available from most reverse osmosis manufacturers. However, seawater units are significantly more costly ($ 540 - $ 2400) than tapwater

units ($90 - $ 100). Also, the seawater units require higher operating pressure (800-1000 psig) compared to the tapwater units (60-90 psig). Second, if tapwater units are to be used, the amount of chlorides should be reduced prior to the final tapwater unit. This can be accomplished by passing the waste through a series of 2 or 3 tapwater units. Lastly, it is expected a large amount of the total dissolved solids are due to the high amount of emulsified oil in bilge wastes. Incorporating demulsifying agents and/or air flotation would reduce the amount of dissolved solids and increase the efficiency of the reverse osmosis unit.

As indicated in Tables 5.1 through 5.3 the *tapwater* reverse osmosis membrane significantly reduced chlorides, zinc, and barium. The results indicate that reverse osmosis was not very efficient at removing manganese, nickel, lead and thallium. Mixed results were recorded for the reduction in copper and total organic carbon (TOC). Results of the GT sample showed significant reductions in copper and TOC from reverse osmosis treatment. However, results of the SB samples showed only a slight reduction in copper and a tremendous *increase* in TOC after reverse osmosis treatment. Since the results were replicated, contamination of the sample must have occurred. The GT and SB samples contained very similar amounts of copper (0.6 and 0.5 ppm) after passing through the reverse osmosis unit. This indicates that the removal capacity of the reverse osmosis unit, for copper, is around 0.5 ppm. Therefore, the reason the GT

sample had a much higher copper reduction (relative to the SB sample) was because it had a much higher *initial* copper concentration than the SB sample. However, the same cannot be said for the TOC results. Reverse osmosis should *not* increase the TOC content of the bilge waste. The TOC results suggest further research in TOC reduction by reverse osmosis is needed.

5.3 Reverse Osmosis Analysis

5.3.1 General

For reasons mentioned earlier, reverse osmosis was the interim mechanism chosen to reduce chlorides, organics, and zinc. Further processing of the bilgewater by reverse osmosis has other significant advantages (reuse, greater pollutant removal) and disadvantages (increased sludge and treatment cost). Reuse systems have been gaining interest worldwide as the potable water supply becomes more and more scarce. Although the Navy at Pearl Harbor, produces its own water, it may face supply shortages in the future.

As mentioned previously, treating all bilgewater with reverse osmosis produces water that is significantly higher in quality than the Ft. Kamehameha pretreatment requirements dictate. Thus, treating all the bilgewater volume is excessive and cost-inefficient. However, it is possible to separate and treat some portion of the total bilgewater volume and then mix the treated effluent back into the remaining bilgewater flow. Splitting the flow would

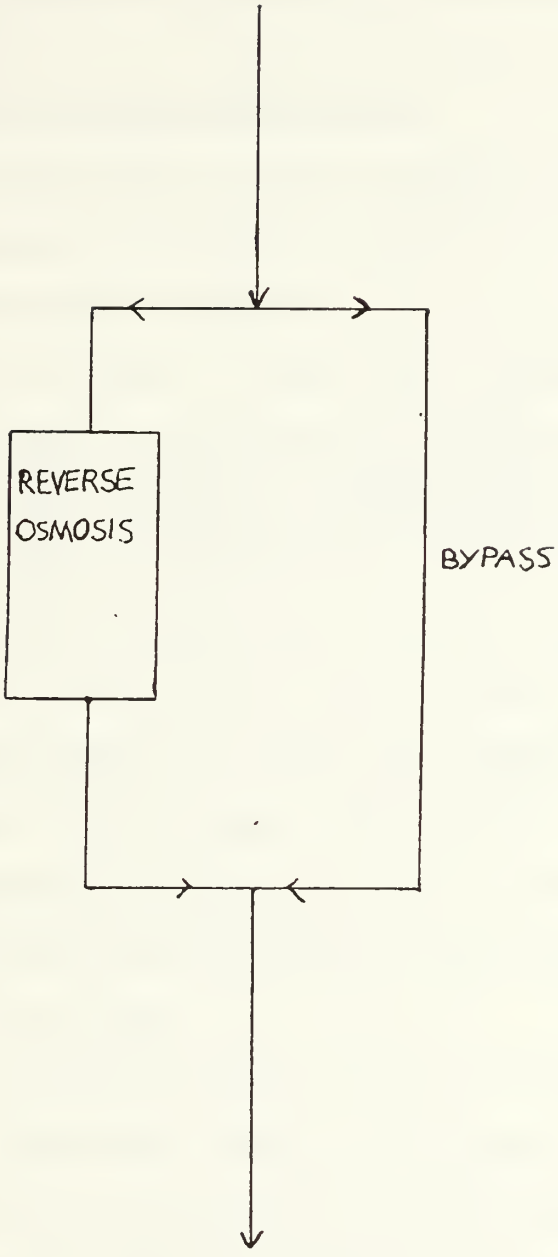


Figure 5.2
Process Flow Sheet for Partial Reverse Osmosis Treatment

maximize efficiency and minimize the required treatment. Figure 5.2 shows the concept of splitting the flow of the bilge waste

5.3.2 Reverse Osmosis Efficiency

Utilizing table 4.1 the greatest treatment gained for sewer disposal is chloride. Therefore incorporating a mass balance equation as follows:

$$(Q_{total})(Z_{stnd}) = (Q_{ro})(Z_{ro}) + (Q_{total} - Q_{ro})(Z_{feed})$$

where,

Q_{total} = Average daily bilge waste generation rate
Q_{ro} = Portion of Q_{total} passed through R.O. unit.
Z_{stnd} = Maximum allowable Chloride concentration.
Z_{ro} = Chloride conc. of R.O. effluent.
Z_{feed} = Chloride conc. of untreated bilgewater.

The percentage of volume that is required to pass through the reverse osmosis unit is 56%. Then, the minimum size of the reverse osmosis unit should be based on 56% of the design flow (200,000 gpd). Therefore, a reverse osmosis unit, discharging directly into the sewer system, should be capable of handling the maximum discharge from the holding tanks of 85,000 gpd.

Utilizing bilgewater as source of water supply does have some drawbacks. Namely, the amount of bilgewater available for reclamation at any one time is highly inconsistent. Although significant volumes are generated annually, the flow generated is anything but consistent. Zero bilgewater is collected on some days, while on other days 22,000 to over 170,000 gpd are collected. During the summer, or dry, months the monthly flow of bilgewater consistently averages close to 37,000 gpd. During the

winter, or usually wet, months the monthly flow averages approximately 85,000 gpd. However, demand for landscape irrigation water is higher in the summer and lower and in the winter. Pearl Harbor consumed an average of 7.1 billion gallons of potable water annually over each of the last 3 years (Public Works Center, 1991).

Water reuse standards dictate the level of treatment required. In Table 5.4 typical reuse water standards are listed for landscape irrigation, vehicle washing, and industrial uses on military installations (Middlebrooks 1982, 472). The difference between Table 5.4 and Table 2.1 is the amount of treatment required in order to reuse the bilgewater for landscape/agricultural purposes.

Compared in Table 4.1 are the maximum pollutant levels for discharge into Ft. Kamehameha and the concentrations typically found in bilgewater. The removal efficiencies of reverse osmosis by pollutant are shown in Table 5.5. Multiplying the removal efficiencies from Table 5.5 by the concentrations typically found in the bilgewater, indicates the effluent water quality achievable by using reverse osmosis to treat bilgewater (Table 5.6).

5.3.3 Reverse Osmosis Economics

Evaluation of the bench scale experiment (Subsection 5.2.3) indicated that the water must pass a series of two tapwater reverse osmosis units or pass through one or two seawater reverse osmosis units. Annual energy requirements to pump the bilge waste through the reverse osmosis units

Table 5.4

Typical Water Reuse Standards

	Concentration (mg/l)*				
	Laundries	Fire Protection	Irrigation	Boilers	Wash Rack
pH	6 - 6.8	5.0 -9.0	4.5 - 9.0	>9.0	n/a
Oil & Grease	10	1.0	30	0.0	5
Suspended Solids	30	10	50	10	10
Beryllium	n/a	0.1	3	2	n/a
Cadmium	n/a	n/a	n/a	20	n/a
Chromium	0.5	n/a	n/a	n/a	n/a
Copper	1.0	n/a	n/a	n/a	n/a
Chloride	n/a	n/a	350	200	600
Cyanide	0.2	0.1	0.01	0.5	0.5
Iron	1.0	5.0	10	0.5	40
Lead	0.5	n/a	n/a	n/a	1
Zinc	0.5	n/a	n/a	n/a	n/a

*(Middlebrooks 1982, 472)

Table 5.5

Removal Efficiency of Reverse Osmosis by Pollutant

Pollutant	Mean Removal Efficiency (%)*
Total Suspended Solids	>88
Oil and Grease	>40
Beryllium	42
Cadmium	13
Chromium	44
Copper	74
Cyanide	43
Lead	31
Mercury	>21
Nickel	46
Selenium	>76
Silver	31
Thallium	46
Zinc	79
Solvents and Toxic Organics	Median range (20 - 51%)

*(U.S. EPA 1980, p. III.6.9-3).

Table 5.6

Achievable Water Quality with Reverse Osmosis

Contaminant	Expected, Average Bilge Waste Contamination after Reverse Osmosis Treatment (mg/l)
Beryllium	<0.018
Cadmium	0.035
Chromium	0.206
Copper	0.346
Lead	<0.304
Mercury	<0.008
Nickel	<0.864
Silver	<0.028
Zinc	1.067
Solvents	0.334 - 0.524*
Total Toxic Organics	4.150 - 6.776*

*Range depends on specific organics present.

were calculated by using a flow rate of 55,000 gpd and various operating pressures. The pump was assumed to be an axial pump with the same diameter as the inlet and outlet pipe. Therefore, the following equation applied:

Work = (Flow) x (Pressure Gradient)

where, Flow = flow rate of bilge waste in cfs
Pressure gradient = increase in water pressure from inlet to outlet in psi.
and, Work = Energy in (ft-lb)/sec.

Work units were then converted into kilowatts. The kilowatts were then converted into kilowatt hours (kwH), assuming continuous (24 hours a day) operations. Table 5.7 summarizes the economic comparison of the different reverse osmosis units.

Table 5.7
Costs of Various Reverse Osmosis Units to Treat Bilge Waste at Pearl Harbor

Reverse Osmosis Unit Type	Number Required	Cost per Unit*	Annual Energy Cost** Per Unit	Total
Tapwater unit (90 psi)				
TW30-1812	60	$100	$1,179	$70,740
Seawater (800 psi)				
SW30-4021	2	$540	$11,220	$22,440
SW30-8040	1	$2348	$11,220	$11,220

*Applied Membranes, Inc.; telephone quote on 02 July 1992.
**Energy costs are calculated using the $0.09681/KWH which the Navy Public Works Center charges all activities to whom the it supplies electric power.

Clearly, the most cost-effective unit for bilge waste treatment, as shown in Table 5.7, is the SW30-8040. The cost, although small, could be avoided if the Navy were to utilize one of its existing portable reverse osmosis units.

5.4 Holding Tank Analysis

5.4.1 System Design

Storage reservoirs (or holding tanks) are used to ensure a constant flow of liquid, even during low periods. Load equalization is important for effective treatment of wastewaters. A treatment system operates most effectively when it can be designed for a specific, constant flow rate. Load equalization also reduces the impact of "spikes," or a slug of highly-contaminated waste, on the treatment system. Storage tanks also allow the waste to be held until testing results are complete prior to release the waste for treatment.

Storage of bilge waste prior to oil/water separation is important for the above reasons. However, since gravity-separation of the oil and water will occur with the holding tank, the tank must be equipped with floating oil skimmers and scum/sludge skimmers. Demulsifying agents may be added in the holding tank.

Sufficient storage tank capacity is essential. If the tank capacity is insufficient, there will be insufficient time to test the tank contents, and higher or non-equalized outflows will be required. Therefore, the storage capacity required must be determined.

The concentration of contaminants entering and leaving a storage tank are seldom equal. This is because the holding tank also acts a large settling basin. The longer the water is held the greater the volume of contaminants

that will settle to the bottom of the holding tank, where they stay until forcibly removed. Thus removal of some suspended solids occurs within the holding tanks. Generally, the dissolved solids remain constant between the inflow and outflow, while suspended solids concentrations will fluctuate.

5.4.2 Storage Requirements

The first requirement is to determine the size of the tank required. The following mass-balance equation was used to determine the storage capacity required:

$$V_{delta} = (Q_{in} - Q_{out})\ (t)$$

where, V_{delta} = change in volume (gal.) within tank
Q_{in} = flow (gpd) into tank
Q_{out} = flow (gpd) out of tank
t = duration (days) of Q_{in}

The inflow rates were taken from Table 20 and averaged over 7 days ($t = 7$). The result was a set of 52 weekly average inflow rates, Q_{in}. The outflow rate (Q_{out}) is set constant to equalize the load into the treatment systems.

Usually a desired outflow rate is known prior to determining the tank capacity. However, as the holding tanks already exist, in this case the required outflow rate was determined based on the total storage capacity. The existing tanks have a storage capacity of 1.575 million gallons each. One tank should be used while the other tank is being tested or cleaned.

Since there exists such a large flow variation between spring/summer and fall/winter, two outflow rates were

chosen: one for the light months (spring/summer) and another one for the heavy months (fall/winter). Since each of the two outflow rates will be used continuously for several months, the load is essentially equalized.

Table 5.8 shows the changes in the holding tank volume, based on the above-determined outflow rates. Table 5.8 shows that the storage tank capacity, at those specific outflow rates, will never be exceeded nor will the tank be completely emptied more than once.

5.4.3 Pollutant Concentrations at Holding Tanks

Inflow and outflow concentrations of pollutants will differ due to settling of contaminants in the tank. Dissolved solids will tend to stay with the water and therefore the dissolved solids content will not differ much between the inflow and the outflow. Suspended solids, on the other hand, tend to settle from the water, causing the suspended solids content to differ between the inflow and outflow. Ft. Kamehameha typically receives waste with a suspended solids content between 200 and 500 mg/l. Bilge waste typically contains 50 to 500 mg/l (*Military Handbook* 1988). Two samples taken from ships in Pearl Harbor contained just slightly more than 100 mg/l (114 mg/l) suspended solids (Appendix C). Therefore, concentration variations, due to settling in the tank, will not affect the treatability of the bilge waste.

Table 5.8
Volume Requirements for Holding Tanks

week	Cummul. volume (gal)	week	Cummul. Volume (gal.)
0	962500	27	1096298
1	872900	28	1136198
2	861000	29	1176098
3	849100	30	1264095
4	837200	31	1138998
5	825300	32	954695
6	813400	33	737093
7	801500	34	530593
8	815500	35	257495
9	829500	36	28798
10	843500	37	0
11	857500	38	402703
12	871500	39	631428
13	885500	40	745325
14	899500	41	570325
15	913500	42	630525
16	927500	43	703850
17	941500	44	743750
18	955500	45	824348
19	969500	46	882749
20	983500	47	978152
21	997500	48	1143849
22	1011500	49	1209649
23	1025500	50	1301349
24	1039500	51	1318947
25	1053500	52	1347745
26	1067500		

5.5 Sulfide/Odor Control

The treatment of oily waste can produce Hydrogen Sulfide gas (H_2S), which is both toxic and noxious. In order to prevent the formation of hydrogen sulfide the bilge waste must be further treated. A study was conducted at the Naval Supply Center's oily waste treatment facility to determine the best methods to suppress the formation of hydrogen sulfide.

The study suggested that chemical oxidation was the best method for odor control (Sunn, Low, Tom & Hara, Inc. 1975). In particular, oxidation by the addition of 2 lbs. hydrogen peroxide per lb. of hydrogen sulfide was recommended. The estimated costs for this form of odor control in 1975 were $20,000 for capital costs and $111 per day ($40,600 annually) in operating costs (Sunn, Low, Tom & Hara, Inc. 1975).

5.6 Interim Solution

5.6.1 Description and Performance

Based on the foregoing, it is now possible to recommend, in detail description, an interim solution and to predict its performance. Figure 5.3 is a schematic representation of the recommended solution. Initially the bilge water would be collected pierside by SWOBs and pump trucks, and transported to NSC. Demulsifying agents would then be added to the bilge waste. The oil/water separation will take place at an NSC oil/water separation facility.

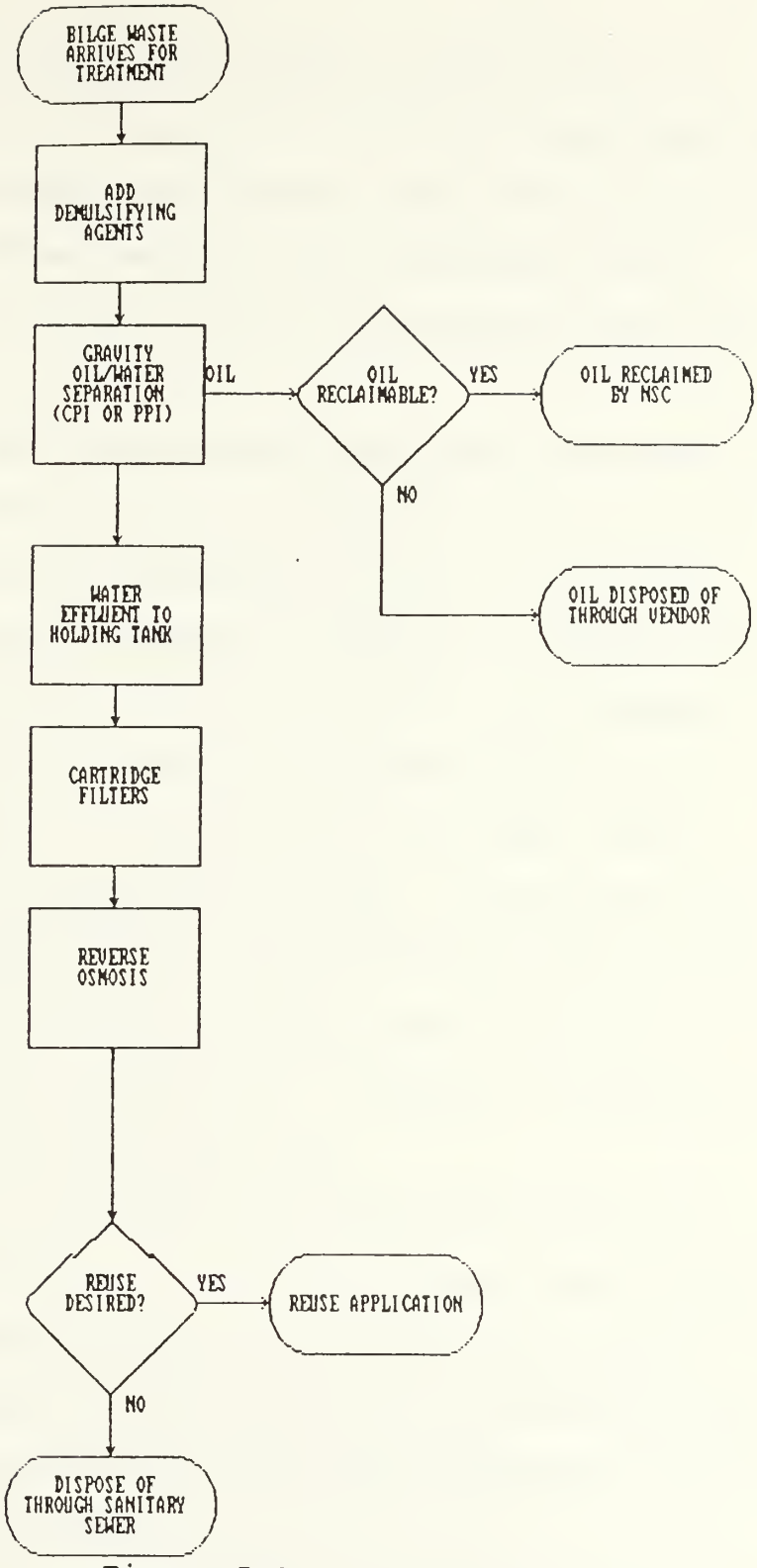


Figure 5.3

Process Flow Sheet for Interim Solution

After separation, the water effluent is then pumped to holding tank. The separated bilge waste is then pumped from the tank at a constant rate through a prefilter and reverse osmosis units. Bilge waste is then discharged into the sanitary sewer on its way to the Ft Kamehameha wastewater treatment plant.

Demulsification and sedimentation alone will remove 60 to 95% of the free oil and 50 to 90% of the emulsified oil (Patterson 1985, 279). Performance of the holding tank, oil/water separator is expected to produce an effluent with an oil content of 60 to 99% of the influent oil content (Patterson 1985, 279). Therefore, by combining the two methods, the removal of the free oil would range from a minimum of 84% to a maximum of over 99%. Emulsified oil removal would range from 50 - 90% (using the median values, a removal rate of 95% of the free oil, and 70% of the emulsified oil can be expected.). "Floatable" suspended solids will be removed with the oil.

The prefilter will remove all suspended solids, by definition, since the 45-um pore-size filter is the standard by which all suspended solids are measured and removed. It is expected that some of the zinc will also be removed by the prefilter. The prefilter will also prolong the life of the reverse osmosis element.

The expected performance of the SW30-8040 reverse osmosis unit was calculated using the mass balance equation mentioned in Subsection 5.3.2. The mass balance equation

was based on 44% of the bilge waste bypassing the reverse osmosis unit. The expected removal performance for the pollutants of concern is listed in Table 5.8. Additionally, the Navy and Marine Corps have extensive experience in operating reverse osmosis units, and possess numerous large-scale, portable units. The portable units can later be returned to their original purpose, when a permanent solution is in place.

The effluent from the reverse osmosis unit can then be discharged directly into the sewer. The discharge would require a 12" pipe and a pump to deliver the water from the reverse osmosis unit to the sanitary sewer.

5.6.2 Costs

The cost data presented in Chapter 4 was obtained from different sources which were published at different times. These costs were updated using the *Engineering News Record* annual cost indices.

Costs for the recommended solution are shown below in Tables 5.9 and 5.10. Demonstrated in Table 5.9 are the capital costs to construct the interim treatment system. The annual operating costs of the system are shown in Table 5.10. These tables indicate that the recommended solution, for the interim, would cost approximately $987,240 to build and another $212,700 annually to operate.

Table 5.9
Capital Cost of Recommended Interim Solution

Process	Cost
Collection:	
(4 new pump trucks)	$240,000
Treatment:	
Holding Tank	$346,000
Oil/Water Separation	$ 16,580
Prefilter	$157,460
Reverse Osmosis	$ 2,400
Disposal:	
Pump through pipe, into sewer	$224,800
Total =	$987,240

Table 5.10
Annual Cost* of Recommended Interim Solution

Process	Cost
Collection:	
Pump trucks (4 ea.)	$ 27,000
Treatment:	
Demulsification	$ 93,500
Oil/Water Separation	$ 17,580
Prefilter	$ 52,220
Reverse Osmosis	$ 11,200
Disposal:	
Energy to pump waste into sewer	$ 11,200
Total =	$ 212,700

*Costs include operation, maintenance, and fee costs.

5.7 Sludge Generation

Sludge will be produced, using the treatment train shown in Figure 6.1, at three locations. Those locations are the OWS, the filter, and the reverse osmosis unit. Sludge produced at the OWS is considered to be recyclable oil. This sludge is therefore a valuable commodity, which NSC converts to recycled oil.

Filtration with a 45 *um* pore-size filter removes all the suspended solids by definition. The concentration of suspended solids, determined from the bench-scale experiment, was 114 mg/l. Thus during the average flow of 55,000 gpd, the amount of sludge generated would be 52 lb. per day.

For reverse osmosis, the reduction in chlorides (approximately 9,600 mg/l reduction) is far greater than the combined reduction of all the other pollutants. Reduction of all the non-chloride pollutants, combined, would account for less than 100 mg/l. Therefore a sludge production of 9,700 mg/l is expected. This is an average of 4,452 lb. (dry weight) produced daily at the average bilge waste flow of 55,000 gpd.

Thus, the total amount of sludge produced from the treatment of bilge wastes is expected to be approximately 4,500 lb (dry weight). This sludge could be treated and disposed of with the Ft. Kamehameha WWTP sludge.

5.8 Summary

Based on the foregoing, the recommended interim solution is the addition of demulsifying agents, then treatment by coalescing gravity oil/water separation with the effluent then routed into a holding tank, before being passed through a prefilter unit, a reverse osmosis unit, and then discharged into the sanitary sewer system. This interim treatment system is expected to cost about $1

million to build and $200,000 annually to operate and maintain.

CHAPTER 6
RECOMMENDED PERMANENT SOLUTION

6.1 Reasons for a More Permanent Solution

There are potential problems associated with the proposed interim solution. The three major concerns are the ability of Ft. Kamehameha WWTP to accept the added inflow, costs associated with chloride removal, and the possible future classification of oily waste (such as bilgewater) being classified as hazardous waste.

If Ft. Kamehameha cannot accept the additional load, or if oily waste is classified as hazardous waste, the interim solution no longer is a viable option. Chloride removal is not necessary if the bilgewater is discharged into a marine environment. If oily waste becomes a classified hazardous waste, the bilgewater may be classified as hazardous until the used oil fraction is satisfactorily removed by a hazardous waste-permitted facility. This would require more extensive oil removal, continuous effluent monitoring, and other requirements prior to discharge into the sewer system.

Due to the above concerns, the interim solution is proposed only for such duration as required to implement a permanent solution. An optimal permanent solution would be to separate the oil in a separate facility capable of obtaining a hazardous waste permit for removing used oil from bilgewater. Additionally, the permanent solution should have the final effluent directly discharged (under

NPDES permit) into marine waters, instead of applying the additional load to Ft. Kamehameha WWTP.

The two major reasons for direct discharge is 1) that chlorides would not be required to be removed and 2) to reduce the burden on the Ft. Kamehameha WWTP which is already operating at or near capacity. The removal of chlorides, or desalting, is an expensive process. Secondly, a dedicated treatment and discharge facility for the bilge wastes will not overburden the Ft. Kamehameha treatment plant.

6.2 Permanent Solution

6.2.1 Description and Performance

A suggested method would include separation of the oil from the bilgewater by means of a coalescing gravity OWS (again, there currently exists no available OWS). The OWS effluent should then be prefiltered, prior to entering granular activated carbon filters to remove solvents, TTO, and any heavy metal contaminants. This process should adequately pretreat the bilgewater to allow the bilgewater to be discharged into the sanitary sewer system. This solution is charted in Figure 6.1.

6.2.1.1 Oil/Water Separation

The oil/water separator used for the interim solution, should continue to be utilized in the permanent solution.

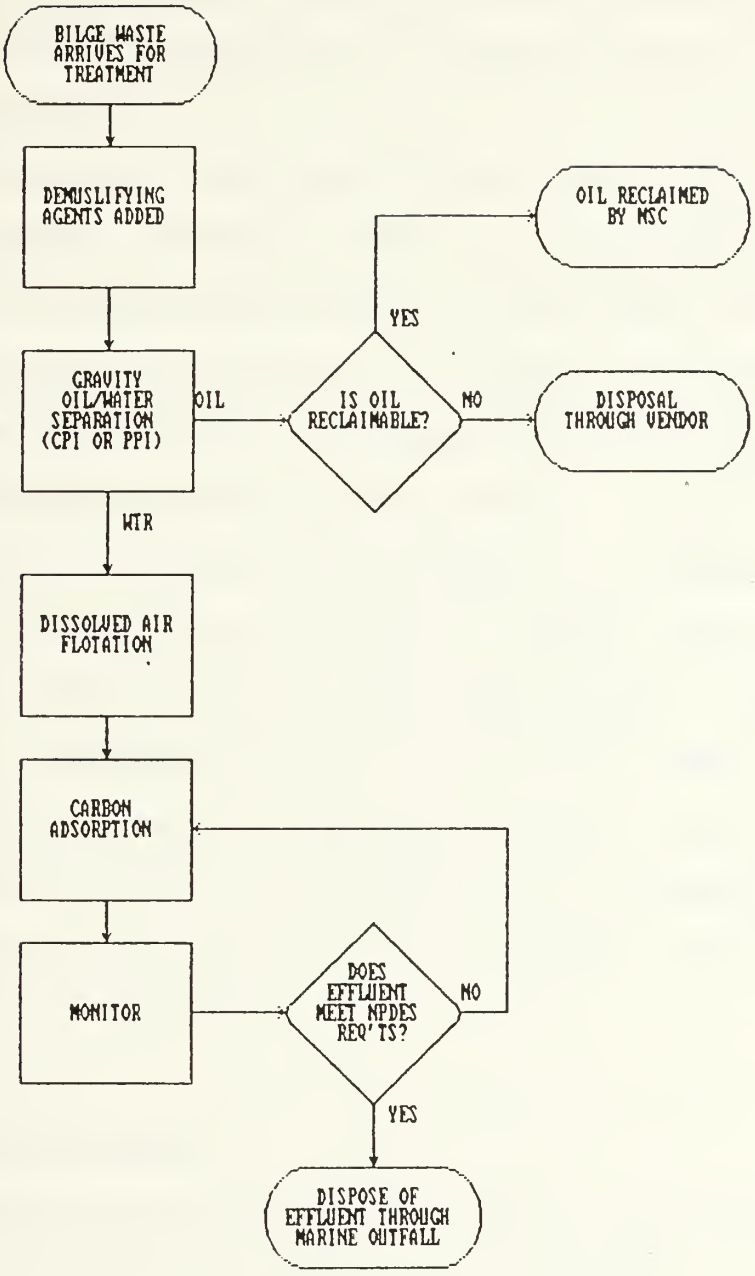


Figure 6.1
Process Flow Sheet for Permanent Solution

6.2.1.2 Solvent and Toxic Organics Removal

Steam/air stripping requires very extensive operation and maintenance effort. The atmospheric release of the pollutants with the steam or air also presents an air pollution concern.

Filtration is very effective at removing solvent and TTO pollutants. However, there is no significant data relating filtration performance to flow rates over 30,000 gpd. Although it is possible to install multiple filtration units, the cost for the units and pretreatment to avoid membrane fouling would be prohibitive.

Activated carbon is very effective at removing organics associated with solvents and TTO. However, activated carbon requires minimal insoluble oil concentrations and is expensive. Filtration prior to activated carbon treatment is required if suspended solids are greater than 50 pp.

Solvent or TTO removal would best be accomplished by either granular or powder activated carbon, and following the oil/water separation.

6.2.1.3 Zinc Removal

Chemical precipitation with lime is the common means of removing zinc, where recovery is not required. Chemical precipitation is expensive, requires constant adjustment of chemicals to obtain proper pH, and generates large volumes of sludge.

Ion exchange is the common method for recovering zinc from wastewaters. However, according to Patterson, "Unless associated with other materials that are costly to treat and replace,...zinc treatment by ion exchange for the recovery value of the metal alone is not economical" (1985, 445). Therefore ion exchange is not considered a viable option for zinc removal.

Reverse osmosis is capable of removing zinc and salt from the wastewater. Reverse osmosis is relatively inexpensive, in terms of capital investment. However, reverse osmosis is energy intensive and requires pretreatment and maintenance to prevent membrane fouling.

Activated carbon, as mentioned earlier, can also be used to remove solvents and TTO. Thus it should be possible to remove zinc along with solvent and TTO. However, this will increase the rate of regeneration required, as the more removal the carbon filters perform the faster the carbon is exhausted. Additionally, the effect of the saline water on the activated carbon treatment is unknown.

Evaporation is an energy intensive operation, which is relatively, mechanically-complex. Evaporative procedures are not well-established for zinc removal and also raise an air-emissions concern.

Electrolysis allows simple and direct removal of zinc from wastewaters. A minimum retention time is required for effective removal of zinc. However, the method is selective for specific metals vice removing a range of metals or

pollutants. Additionally, this process has not been widely used and results of full-scale operations are not available.

For zinc removal, proven effectiveness at large volumes indicates the viable options are activated carbon (see also solvent and TTO removal above), reverse osmosis, and chemical precipitation, in that order.

6.2.2 Performance Summary

The expected performance of the permanent treatment solution is detailed in Table 6.1.

6.3 Summary

Based on the foregoing, it is recommended that a permanent, long-term solution be pursued to replace the interim solution. The recommended permanent solution is for the bilge waste to treated by oil/water separation, prefiltration, and activated carbon filtration. Direct marine disposal of the effluent, under an NPDES permit, is recommended after treatment.

Table 6.1
Expected Performance of Recommended Permanent Solution

Contaminant	% Reduction Expected*	Removal Mechanism
Oil/Grease	99%	Coalescing filter Air Flotation
Beryllium		Prefilter/Adsorption
Cadmium	0%	
Chromium	92%	Activated Carbon
Copper	92%	Activated Carbon
Lead	58%	Activated Carbon
Mercury	90%	Activated Carbon
Nickel	97%	filtration
Silver	0%	
Zinc	77%	Prefilter/Adsorption
Solvents	99%	Activated Carbon
Total Toxic Organics	99%	Activated Carbon

*(Patterson 1985)

CHAPTER 7
CONCLUSION

7.1 Summary of Recommendations

The U.S. Navy has decided to discontinue using "donuts" in the collection, treatment, and disposal of bilge waste. However, before the U.S. Navy can discontinue using donuts a suitable alternative to the use of donuts must be found and implemented. This thesis formulated various alternative methods to the use of donuts at Pearl Harbor. Two of the methods were recommended. One alternative method was recommended as an interim solution, and the other method was recommended as a permanent solution.

The recommended interim solution for Pearl Harbor was to dispose of the bilge waste via an existing sanitary sewer system. However, any discharge into the sanitary sewer at Pearl Harbor must meet certain water quality requirements. Therefore, an interim treatment process is required prior to disposal.

The recommended interim treatment train is; load equalization tanks with the addition of demulsification agents, coalescing oil/water separation, cartridge filters, and reverse osmosis. The first step in treating the bilge waste, after collection and transportation, is the removal of oil. The removal of oil must allow the oil to be reclaimed and recycled, as oil recovery/recycling is an important factor in Navy operations. Recommended oil/water separation is to be achieved using demulsification agents to

reduce levels of emulsified oils, and holding tanks and coalescing filters to remove the free and "demulsified" oils. The remaining pollutants of concern, for sanitary sewer disposal, are to be removed using a cartridge filter to remove suspended solids and a reverse osmosis unit to remove dissolved solids (chlorides), metals (such as zinc), and some organics (such as trichloroethane).

Prior to treatment, bilge waste must be collected and transported to the treatment facility. The recommended interim solution is to collect and transport the bilge waste using already existing Ship Waste Offload Barges, and newly purchased or leased pump trucks (15,000 gal capacity). Pump trucks represent the most economical collection and transportation system that is immediately available.

The second alternative method, a permanent solution, recommended disposal through a marine outfall, after treatment. Marine disposal was recommended since the local wastewater treatment plant is already operating at, or near, capacity. Treatment was recommended by using the same methods as mentioned above, except replacing reverse osmosis units with activated carbon. This was recommended since chloride removal is not required for marine disposal, and since activated carbon is more efficient, in terms of cost and performance, at removing organics.

7.2 General Applications

It is well-accepted both within and outside the Navy community that the use of donuts to handle bilge waste is

not an acceptable water quality management tool. This thesis estimates that 20 Million gallons of bilge waste are generated annually at Pearl Harbor alone. Larger ports, such as San Diego and Norfolk, undoubtedly generate much greater volumes of bilge waste. It is due to the potential environmental impact of these wastes on the water quality inside and around the U.S. Navy's ports that has prompted the Commander in Charge of the Pacific Fleet to place the issue of proper water quality management of bilge wastes on the "front burner" of Navy environmental issues (U.S. Navy, CINCPACFLT Admininstrative Message of 06 Jul 91).

It is recommended that the use of donuts be discontinued, as soon as practicable, in all Navy and civilian ports. Donuts should be replaced with a water quality management that ensures bilge wastes do not adversely affect the quality of receiving waters.

APPENDIX A
LIST OF CONTAMINANTS FOR WHICH BILGE WASTE WAS TESTED

Table A.1
List of Contaminants for which Bilge Waste was Tested*

1,1-Dichloroethane
1,1-Dichloroethene
1,1,1-Trichloroehtane
1,1,2-Trichloroethane
1,1,2,2-Tetrachloroethane
1,2-Dichlorobenzene
1,2-Dichloroethane
1,2-Dichloropropane
1,2,4-Trichlorobenzene
1,3-Dichlorobenzene
1,4-Dichlorobenzene
2-Chloroethylvinyl ether
2-Chlorophenol
2-Nitrophenol
2,4-Dichlorophenol
2,4-Dimethylphenol
2,4-Dinitrotoluene
2,4,6-Dichlorophenol
2,4-Dinitrophenol
2,6-Dinitrotoluene
2-Chloronapthalene
3,3'-Dichlorobenzidene
4-Bromophenyl phenyl ether
4-Chloro-3-methylphenol
4-Chlorophenyl phenyl ether
4-Nitrophenol
4,4'-DDE
4,4'-DDT
4,6-Dinitro-2-methylphenol
Acenapthene
Acenapthylene
Aldrin
-BHC
-Endosulfan
Ammonia
Anthracene
Antimony
Arochlor 1248
Arochlor 1260
Arochlor 1232
Arochlor 1221
Arochlor 1254
Arochlor 1242/1016
Arsenic
Barium
Benzene
Benzidine
Benzo(a)anthracene
Benzo(a)pyrene
Benzo(b)fluoranthene
Benzo(g,h,i)perylene
Benzo(k)fluoranthene
Beryllium
-BHC
-Endosulfan
Biochemical Oxygen Demand
Bis(2-ethylexyl)phthalate
Bis(2-chloroethoxy)methane
Bis(2-chloroethyl)ether
Bis(2-chloroisopropyl)ether
Bromomethane
Bromodichloromethane
Bromoform
Butylbenzyl phthalate
Cadmium
Carbon tetrachloride

*Twenty-two of the 114 samples were tested for all the parameters listed in this table. The remaining were then tested for a subset of the parameters listed in this table.

Table A.1 (Continued)
List of Contaminants for which Bilge Waste was Tested*

Chemical Oxygen Demand
Chlordane
Chlorobenzene
Chloroethane
Chloroform
Chloromethane
Chromium
Chrysene
Cis-1,3-dichloropropene
Copper
Cyanide
4,4'-DDD
-BHC
Di-n-butyl phthalate
Di-n-octyl phthalate
Dibenz(a,h)anthracene
Dibromochloromethane
Dieldrin
Diethyl phthalate
Dimethyl phthalate
Endosulfan sulfate
Endrin
Endrin Aldehyde
Ethylbenzene
Fecal Coliform
Fluoranthene
Fluorene
-BHC
Heptachlor epoxide
Heptachlor
Hexachlorobenzene
Hexachlorobutadiene
Hexachlorocyclopentadiene
Hexachloroethane
Indeno(1,2,3-cd)pyrene
Iron
Isophorone
Lead
Manganese
Mercury
Methyl chloride
N-nitrosodi-n-propylamine
N-nitrosodimethylamine
N-nitrosodiphenylamine
Naphthalene
Nickel
Nitrobenzene
Oil and Grease
Pentachlorophenol
Phenanthrene
Phenol
Pyrene
Selenium
Silver
Tetrachloroethene
Thallium
Toluene
Total Suspended Solids
Total Organic Carbon
Total Phenols
Toxaphene
Trans-1,2-dichloroethene
Trans-1,3-dichloropropane
Trichloroethene
Trichlorofluoromethane
Vinyl Chloride
Zinc

*Twenty-two of the 114 samples were tested for all the parameters listed in this table. The remaining were then tested for a subset of the parameters listed in this table.

APPENDIX B
BILGE WASTE GENERATION DATA

B.1 Generation Data

The daily determinations of the bilge waste generated at Pearl Harbor were based on ships' berthing data, as explained in Chapter 3. The monthly generation data was based on the sum of the daily data for each month.

The estimated amount of bilge waste generated daily and monthly is listed in Tables B.1 and B.2, respectively, for Pearl Harbor. As a rough check on the accuracy of the estimated amount of bilge waste generated, an estimate of the oil recovered at the Pearl Harbor NSC was also performed.

B.2 Oil Recovered from Bilge Waste

In order to check the accuracy/validity of the estimated annual bilgewater generation, the volume of oil recovered from bilgewater by the Naval Supply Center was determined. This should be between 1 and 5% of the generated bilgewater volumes.

The Naval Supply Center recovered approximately 820,842 gallons of "used oil" in the calendar year 1991 from bilgewater, which equates to 4.1 % of the estimated total bilgewater generated. Approximately 10% of the used oil arrived at NSC directly by donuts and pump trucks. The remaining oily waste was delivered by SWOBs. The SWOBs contained not only bilge waste but also used oil from

Table B.1
Daily Bilge Waste Generation at Pearl Harbor

ESTIMATED BILGE WASTE GENERATED 22 FEB 91 - 2
(VOLUMES IN GPD)

Date	Bravo	Hotel	Kilo	Mike	Total
FEB22	18500	3700	0	3700	25900
23	18500	0	0	3700	22200
24	18500	0	0	3700	22200
25	18500	0	0	3700	22200
26	18500	0	0	3700	22200
27	18500	0	0	3700	22200
28	18500	0	0	3700	22200
29	18500	0	0	3700	22200
MAR1	25900	0	0	7400	33300
2	25900	0	0	7400	33300
3	25900	0	0	7400	33300
4	25900	0	0	7400	33300
5	25900	0	0	7400	33300
6	25900	0	0	7400	33300
7	25900	0	0	7400	33300
8	25900	0	0	7400	33300
9	25900	0	0	7400	33300
10	25900	0	0	7400	33300
11	25900	0	0	7400	33300
12	25900	0	0	7400	33300
13	25900	0	0	7400	33300
14	25900	0	0	7400	33300
15	25900	0	0	7400	33300
16	25900	0	0	7400	33300
17	25900	0	0	7400	33300
18	25900	0	0	7400	33300
19	25900	0	0	7400	33300
20	25900	0	0	7400	33300
21	25900	0	0	7400	33300
MAR23	25900	0	0	7400	33300
24	25900	0	0	7400	33300
25	25900	0	0	7400	33300
26	25900	0	0	7400	33300
27	25900	0	0	7400	33300
28	25900	0	0	7400	33300
29	25900	0	0	7400	33300
30	25900	0	0	7400	33300
31	25900	0	0	7400	33300
APR1	25900	0	0	7400	33300
2	25900	0	0	7400	33300
3	25900	0	0	7400	33300
4	25900	0	0	7400	33300
5	25900	0	0	7400	33300
6	25900	0	0	7400	33300
7	25900	0	0	7400	33300
8	25900	0	0	7400	33300
9	25900	0	0	7400	33300

Table B.1 (Continued)
Daily Bilge Waste Generation at Pearl Harbor

ESTIMATED BILGE WASTE GENERATED 22 FEB 91 - 2
(VOLUMES IN GPD)

Date	Bravo	Hotel	Kilo	Mike	Total
10	25900	0	0	7400	33300
11	29600	0	0	7400	37000
12	29600	0	0	7400	37000
13	29600	0	0	7400	37000
14	29600	0	0	7400	37000
15	29600	0	0	7400	37000
16	29600	0	0	7400	37000
17	29600	0	0	7400	37000
18	29600	0	0	7400	37000
19	29600	0	0	7400	37000
20	29600	0	0	7400	37000
21	29600	0	0	7400	37000
APR22	29600	0	0	7400	37000
23	29600	0	0	7400	37000
24	29600	0	0	7400	37000
25	29600	0	0	7400	37000
26	29600	0	0	7400	37000
27	29600	0	0	7400	37000
28	29600	0	0	7400	37000
29	29600	0	0	7400	37000
30	29600	0	0	7400	37000
MAY1	29600	0	0	7400	37000
2	29600	0	0	7400	37000
3	29600	0	0	7400	37000
4	29600	0	0	7400	37000
5	29600	0	0	7400	37000
6	29600	0	0	7400	37000
7	29600	0	0	7400	37000
8	29600	0	0	7400	37000
9	29600	0	0	7400	37000
10	29600	0	0	7400	37000
11	29600	0	0	7400	37000
12	29600	0	0	7400	37000
13	29600	0	0	7400	37000
14	29600	0	0	7400	37000
15	29600	0	0	7400	37000
16	29600	0	0	7400	37000
17	29600	0	0	7400	37000
18	29600	0	0	7400	37000
19	29600	0	0	7400	37000
20	29600	0	0	7400	37000
MAY21	29600	0	0	7400	37000
22	29600	0	0	7400	37000
23	29600	0	0	7400	37000
24	29600	0	0	7400	37000
25	29600	0	0	7400	37000
26	29600	0	0	7400	37000

Table B.1 (Continued)
Daily Bilge Waste Generation at Pearl Harbor

ESTIMATED BILGE WASTE GENERATED 22 FEB 91 - 2
(VOLUMES IN GPD)

Date	Bravo	Hotel	Kilo	Mike	Total
27	29600	0	0	7400	37000
28	29600	0	0	7400	37000
29	29600	0	0	7400	37000
30	29600	0	0	7400	37000
JUN1	29600	0	0	7400	37000
2	29600	0	0	7400	37000
3	29600	0	0	7400	37000
4	29600	0	0	7400	37000
5	29600	0	0	7400	37000
6	29600	0	0	7400	37000
7	29600	0	0	7400	37000
8	29600	0	0	7400	37000
9	29600	0	0	7400	37000
10	29600	0	0	7400	37000
11	29600	0	0	7400	37000
12	29600	0	0	7400	37000
13	29600	0	0	7400	37000
14	29600	0	0	7400	37000
15	29600	0	0	7400	37000
16	29600	0	0	7400	37000
17	29600	0	0	7400	37000
18	29600	0	0	7400	37000
19	29600	0	0	7400	37000
20	29600	0	0	7400	37000
JUN21	29600	0	0	7400	37000
22	29600	0	0	7400	37000
23	29600	0	0	7400	37000
24	29600	0	0	7400	37000
25	29600	0	0	7400	37000
26	29600	0	0	7400	37000
27	29600	0	0	7400	37000
28	29600	0	0	7400	37000
29	29600	0	0	7400	37000
30	29600	0	0	7400	37000
JUL1	29600	0	0	7400	37000
2	29600	0	0	7400	37000
3	29600	0	0	7400	37000
4	29600	0	0	7400	37000
5	29600	0	0	7400	37000
6	29600	0	0	7400	37000
7	29600	0	0	7400	37000
8	29600	0	0	7400	37000
9	29600	0	0	7400	37000
10	29600	0	0	7400	37000
11	29600	0	0	7400	37000
12	29600	0	0	7400	37000
13	29600	0	0	7400	37000

Table B.1 (Continued)
Daily Bilge Waste Generation at Pearl Harbor

ESTIMATED BILGE WASTE GENERATED 22 FEB 91 - 2
(VOLUMES IN GPD)

Date	Bravo	Hotel	Kilo	Mike	Total
14	29600	0	0	7400	37000
15	29600	0	0	7400	37000
16	29600	0	0	7400	37000
17	29600	0	0	7400	37000
18	29600	0	0	7400	37000
19	29600	0	0	7400	37000
20	29600	0	0	7400	37000
JUL21	29600	0	0	7400	37000
22	29600	0	0	7400	37000
23	29600	0	0	7400	37000
24	29600	0	0	7400	37000
25	29600	0	0	7400	37000
26	29600	0	0	7400	37000
27	29600	0	0	7400	37000
28	29600	0	0	7400	37000
29	29600	0	0	7400	37000
30	29600	0	0	7400	37000
31	29600	0	0	7400	37000
AUG1	29600	0	0	7400	37000
2	29600	0	0	7400	37000
3	29600	0	0	7400	37000
4	29600	0	0	7400	37000
5	29600	0	0	7400	37000
6	29600	0	0	7400	37000
7	29600	0	0	7400	37000
8	29600	0	0	7400	37000
9	29600	0	0	7400	37000
10	29600	0	0	7400	37000
11	29600	0	0	7400	37000
12	29600	0	0	7400	37000
13	29600	0	0	7400	37000
14	29600	0	0	7400	37000
15	29600	0	0	7400	37000
16	29600	0	0	7400	37000
17	29600	0	0	7400	37000
18	29600	0	0	7400	37000
19	29600	0	0	7400	37000
20	29600	0	0	7400	37000
AUG21	29600	0	0	7400	37000
22	29600	0	0	7400	37000
23	29600	0	0	7400	37000
24	29600	0	0	7400	37000
25	29600	0	0	7400	37000
26	29600	0	0	7400	37000
27	33300	0	0	7400	40700
28	33300	0	0	7400	40700
29	33300	0	0	7400	40700

Table B.1 (Continued)
Daily Bilge Waste Generation at Pearl Harbor

ESTIMATED BILGE WASTED GENERATED 22FEB91 - 21
(VOLUME IN GPD)

Date	Bravo	Hotel	Kilo	Mike	Total
30	33300	0	0	7400	40700
31	33300	0	0	7400	40700
SEP1	33300	0	0	7400	40700
2	33300	0	0	7400	40700
3	33300	0	0	7400	40700
4	33300	0	0	7400	40700
5	33300	0	0	7400	40700
6	33300	0	0	7400	40700
7	33300	0	0	7400	40700
8	33300	0	0	7400	40700
9	33300	0	0	7400	40700
10	33300	0	0	7400	40700
11	33300	0	0	7400	40700
12	33300	0	0	7400	40700
13	33300	0	0	7400	40700
14	33300	0	0	7400	40700
15	33300	0	0	7400	40700
16	33300	0	0	7400	40700
17	33300	0	0	7400	40700
18	33300	0	0	11100	44400
19	44400	0	0	14800	59200
20	44400	0	7400	14800	66600
21	44400	0	11100	14800	70300
SEP23	44400	0	14800	14800	74000
24	44400	0	11100	14800	70300
25	40700	0	14800	11100	66600
26	44400	0	7400	7400	59200
27	48100	0	3700	7400	59200
28	48100	0	0	11100	59200
29	48100	0	0	11100	59200
30	44400	0	0	11100	55500
OCT1	44400	7400	0	11100	62900
2	37000	7400	0	14800	59200
3	37000	7400	0	14800	59200
4	37000	3700	0	14800	55500
5	37000	3700	0	14800	55500
6	37000	3700	0	14800	55500
7	37000	3700	0	14800	55500
8	37000	0	0	14800	51800
9	37000	0	3700	7400	48100
10	37000	0	7400	7400	51800
11	44400	0	7400	7400	59200
12	40700	0	11100	7400	59200
13	37000	0	14800	7400	59200
14	37000	3700	14800	7400	62900
15	37000	0	14800	7400	59200
16	29600	0	7400	7400	44400

Table B.1 (Continued)
Daily Bilge Waste Generation at Pearl Harbor

ESTIMATED BILGE WASTED GENERATED 22FEB91 - 21
(VOLUME IN GPD)

Date	Bravo	Hotel	Kilo	Mike	Total
17	29600	0	7400	7400	44400
18	40700	0	7400	11100	59200
19	33300	0	7400	7400	48100
20	33300	0	7400	7400	48100
21	37000	0	7400	7400	51800
OCT22	29600	0	0	7400	37000
23	29600	0	3700	7400	40700
24	33300	3700	3700	7400	48100
25	29600	3700	7400	7400	48100
26	37000	3700	3700	7400	51800
27	37000	3700	3700	11100	55500
28	33300	0	3700	11100	48100
29	33300	0	0	11100	44400
30	37000	3700	3700	11100	55500
31	29600	0	7400	11100	48100
NOV1	44400	0	3700	14800	62900
2	44400	0	3700	11100	59200
3	44400	0	3700	11100	59200
4	48100	0	7400	11100	66600
5	51800	0	7400	11100	70300
6	51800	7400	7400	7400	74000
7	51800	3700	7400	3700	66600
8	59200	0	7400	103700	170300
9	37000	0	3700	103700	144400
10	37000	0	3700	107400	148100
11	55500	0	3700	111100	170300
12	55500	3700	3700	111100	174000
13	55500	3700	0	61100	120300
14	55500	3700	0	61100	120300
15	44400	3700	7400	64800	120300
16	44400	3700	3700	68500	120300
17	48100	0	0	68500	116600
18	48100	7400	3700	68500	127700
19	44400	3700	3700	68500	120300
20	44400	0	3700	68500	116600
NOV21	40700	0	0	68500	109200
22	44400	0	0	68500	112900
23	44400	0	0	68500	112900
24	40700	0	0	68500	109200
25	37000	7400	0	64800	109200
26	29600	3700	0	64800	98100
27	29600	3700	0	64800	98100
28	25900	3700	0	64800	94400
29	22200	0	0	64800	87000
30	22200	0	0	64800	87000
DEC1	37000	0	0	7400	44400
2	44400	0	0	7400	51800

Table B.1 (Continued)
Daily Bilge Waste Generation at Pearl Harbor

ESTIMATED BILGE WASTED GENERATED 22FEB91 - 21
(VOLUME IN GPD)

Date	Bravo	Hotel	Kilo	Mike	Total
3	48100	0	0	3700	51800
4	55500	0	0	3700	59200
5	55500	0	3700	0	59200
6	55500	0	11100	0	66600
7	55500	0	11100	0	66600
8	55500	0	7400	50000	112900
9	51800	0	7400	50000	109200
10	40700	3700	3700	50000	98100
11	33300	3700	3700	50000	90700
12	33300	3700	3700	50000	90700
13	37000	0	0	50000	87000
14	37000	0	0	50000	87000
15	37000	0	0	50000	87000
16	44400	0	0	50000	94400
17	44400	0	3700	50000	98100
18	44400	0	3700	50000	98100
19	44400	0	3700	50000	98100
20	48100	3700	3700	50000	105500
DEC21	40700	0	3700	50000	94400
22	33300	0	7400	50000	90700
23	33300	0	7400	50000	90700
24	33300	0	7400	50000	90700
25	33300	0	7400	50000	90700
26	33300	0	7400	50000	90700
27	29600	0	7400	50000	87000
28	29600	0	7400	50000	87000
29	29600	0	7400	50000	87000
30	29600	0	7400	50000	87000
31	29600	0	7400	50000	87000
JAN1	37000	3700	11100	57400	109200
2	37000	7400	11100	57400	112900
3	37000	3700	7400	57400	105500
4	37000	3700	7400	57400	105500
5	37000	3700	7400	57400	105500
6	37000	3700	7400	57400	105500
7	25900	3700	0	57400	87000
8	22200	3700	3700	53700	83300
9	22200	3700	3700	53700	83300
10	22200	3700	3700	53700	83300
11	22200	3700	3700	53700	83300
12	22200	3700	3700	53700	83300
13	33300	7400	0	57400	98100
14	29600	7400	0	57400	94400
15	33300	14800	3700	57400	109200
16	37000	14800	3700	57400	112900
17	44400	7400	0	57400	109200
18	40700	7400	3700	57400	109200

Table B.1 (Continued)
Daily Bilge Waste Generation at Pearl Harbor

ESTIMATED BILGE WASTED GENERATED 22FEB91 - 21
(VOLUME IN GPD)

Date	Bravo	Hotel	Kilo	Mike	Total
19	40700	7400	3700	57400	109200
20	40700	7400	3700	57400	109200
JAN21	40700	7400	7400	57400	112900
22	33300	7400	7400	57400	105500
23	33300	7400	11100	57400	109200
24	33300	7400	7400	57400	105500
25	33300	7400	3700	57400	101800
26	33300	7400	3700	57400	101800
27	40700	3700	3700	57400	105500
28	33300	3700	7400	57400	101800
29	29600	0	3700	61100	94400
30	18500	0	3700	57400	79600
31	18500	0	0	57400	75900
FEB1	33300	3700	3700	57400	98100
2	33300	3700	3700	53700	94400
3	37000	3700	3700	53700	98100
4	25900	3700	3700	57400	90700
5	22200	3700	3700	57400	87000
6	25900	3700	7400	57400	94400
7	44400	11100	11100	57400	124000
8	44400	7400	11100	57400	120300
9	44400	7400	11100	57400	120300
10	44400	3700	7400	57400	112900
11	18500	3700	3700	7400	33300
12	22200	3700	3700	7400	37000
13	72200	3700	0	11100	87000
14	79600	11100	0	11100	101800
15	72200	7400	0	14800	94400
16	72200	7400	0	14800	94400
17	72200	3700	0	14800	90700
18	72200	3700	0	14800	90700
19	68500	3700	0	11100	83300
20	68500	7400	0	11100	87000
FEB21	68500	3700	0	11100	83300

Table B.2
Monthly Bilge Waste Generation

Month/Year	Volume of Bilge Waste Generated (gallons)
March/1991	1,032,300
April/1991	1,073,000
May/1991	1,110,000
June/1991	1,110,000
July/1991	1,147,000
August/1991	1,165,500
September/1991	1,435,600
October/1991	1,628,000
November/1991	3,246,300
December/1991	2,639,300
January/1992	3,092,900
February/1992*	1,923,100*

*3 weeks only.

operations other than shipboard operations. Table B.3 details receipt of recovered oil by NSC.

Input from 14 donuts (via Naval Station) was received in 1991, with volumes typically ranging from 2,300 to 8,000 gal.. Assuming an average of 5,150 gallons each, the donuts accounted for an additional 72,100 gallons. Truck receipts were available for only a five month period. Total oil from the individual truck shipments of bilgewater received over 5 months is 3,900 gallons. Extrapolating to a full twelve months the oil recovered from individual shipments of bilgewater would be 9,200 gallons.

Based on the above the Naval Supply Center received an estimated 820,800 gallons of oil from bilgewater. *Exact* amounts received prior to July 1991 and automation of records were undeterminable. However, reasonable estimates of quantities were available. Additionally the total estimated amount of oil received for the year (821,000 gal.) corresponds to 4.1% of the estimated bilgewater volume generated yearly at Pearl Harbor.

The expected amount of oil in bilgewater is 1 to 5%. Therefore the estimated oil recovery is within the range expected, although somewhat on the high end. However, shipyard operations not related to shipboard operations did contribute used oil to the SWOBs. Since the SWOBs accounted for over 90% of the oil received, it is expected that the actual amount of oil received due to bilge water is significantly less than the 821,000 gal. However, exact

Table B.3
Estimated Oil Recovered from Bilge Waste

Delivered by truck

Date	recovered oil from bilgewater (gallons)	Generator
8/1/91	310	Supship
8/9/91	465	Supship
8/12/91	150	Supship
8/13/91	46	Supship
8/28/91	500	PHNSY
8/29/91	20	Supship
9/4/91	200	Supship
9/23/91	190	Supship
9/27/91	170	Supship
10/11/91	450	Naval Station
11/01/91	170	Supship
11/21/91	500	Supship
11/26/91	300	Supship
11/29/91	150	Supship
12/5/91	130	Supship
12/09/91	100	Supship

Delivered by barge or donut

Date	recovered oil from bilgewater (gallons)	Generator
1/18/91	67,500*	SWOB 11
1/22/91	67,500*	SWOB 12
2/14/91	67,500*	SWOB 11
3/27/91	67,500*	SWOB 11
5/13/91	67,500*	SWOB 11
5/20/91	67,500*	SWOB 12
5/21/91	67,500*	SWOB 11
5/22/91	67,000	SWOB 11
10/2/91	70,000	SWOB 11
10/21/91	65,000	SWOB 11
10/25/91	65,000	SWOB 12
TOTAL	739,500	

*volumes between 65,000 and 70,000 gallons, average of 67,500 gallons was estimated.

figures were not obtainable. It should be noted that bilgewater generation volumes did not include the two carrier groups that were in port for only a few days, nor any submarines. However including these ships would increase the estimated bilgewater volume by only approximately 1.15 million gallons (see attached for calculations and assumptions). The estimated amount of bilgewater generated in Pearl Harbor annually is calculated here to be approximately 19.916 million gallons. San Diego, a significantly larger Navy port, estimates its annual bilgewater generation at 46 million gallons.

Therefore it is expected that the generation volumes estimated here are reasonably accurate.

APPENDIX C

BENCH SCALE STUDY OF PROPOSED INTERIM SOLUTION

C.1 Objective

The primary objective was to determine the effective removal of chlorides from the bilge waste using the reverse osmosis process. Secondary objectives were to determine the removal of other contaminants (zinc, solvents, etc.).

C.2 Materials and Equipment

Samples (4 gal. each).....	Gas Turbine Cruiser Steam Boiler Oiler
Reverse Osmosis Unit.....	FilmTec "FT-30" (See attached data sheet)
Apparatus.....	Piston Pump Needle Valve Pressure gage
Equipment.....	Hach Spectrophotometer and reagents for chloride test

C.3 Sampling Data

Samples were collected on the 26th of May 1992. Five gallons of bilge waste were collected from a gas turbine-powered U.S. Navy cruiser, and another 5 gallons were collected from a steam boiler-powered U.S. Navy oiler. The description of the sampling locations and samples are shown in Table C.1 below.

Table C.1
Sample Collection Data

Sample	Date Time of Collection	Location of Collection	Remarks
GT*	5/26/92 1430	Engine Room	Bilge tanks had just been emptied that morning. Sample was very bottom of bilge tanks.
SB**	5/26/92 1500	Engine Room	Bilge area was very full with very black bilgewater. Crewman said that this bilgewater looked darker and more oily than normal.

*GT = Sample taken from Gas Turbine-driven Ship
**SB = Sample taken from Steam Boiler-driven ship

C.4 Methodology

1. Collection:

This experiment was used to simulate the possible full-scale treatment of bilge waste after oil separation and removal. It was desired to get bilge waste from ships using each of the three main types of propulsion plants (Gas turbine, Steam Boiler, Nuclear). However, the presence of nuclear-powered ships is rare in Pearl Harbor and none were present when these samples were collected. Therefore, bilgewater was collected only from two types of ships. One ship was powered by a gas turbine, and the other by a steam boiler. The samples were collected from the main spaces, in particular the engine rooms, since they represent the largest and most contaminated volumes of bilge waste. Samples were collected in plastic 4 gallon jugs by the author.

2. Initial Analysis

Initial analysis was done by the Navy Public Works Center, Environmental Laboratory, with the exception of chloride determination which was done by the author. Chloride concentrations for both samples were determined using the Hach spectrophotometer method.

3. Filtration

The bilge waste was transferred to a separatory funnel to remove oil and grease. A detention time of 15 minutes per liter was utilized. This was intended to simulate an oil/water separator. After removing the oil, the wastewater was filtered through a paper filter (Whatman 934-AH), with pore sizes of 0.45 um. This initial filtration was done to remove suspended solids which might otherwise foul the reverse osmosis membrane. Filtration prior to reverse osmosis is a common practice. The wastewater is then fed, by a piston pump, through a reverse osmosis filter unit. Figure 5.1 shows the arrangement used to pass the bilge waste through the reverse osmosis unit.

4. Final Analysis

Step 2 was repeated, to determine the quality of the reverse osmosis effluent.

C.5 Miscellaneous Results

In addition to the results presented in chapter 5, Tables C.2 through C.4 present additional results obtained from the bench scale experiment.

Table C.2
Toxicity Characteristic Leaching Procedure for Organic Contaminants Found in Sample GT Prior to Treatment

COMMANDING OFFICER
NAVY PUBLIC WORKS CENTER
CODE 330, ENVIRONMENTAL LAB
ATTN: GREGORY GEBHARDT

ANACON NO : 8698
DATE RECEIVED : 6- 5-92
DATE OF REPORT: 6-16-92
CONTRACT NO: N62755-87-D-2819

D.O.NO. : 265-1
SAMPLE ID: 92-04231

QA/QC OFFICER

TCLP VOLATILE ORGANIC ANALYSIS

	COMPOUND	CASNO	MAX.LEVEL mg/l	AMOUNT mg/l
1.	1,1-DICHLOROETHYLENE	75-35-4	0.7	<0.1
2.	1,2-DICHLOROETHANE	107-06-2	0.5	<0.1
3.	BENZENE	71-43-2	0.5	<0.1
4.	CARBON TETRACHLORIDE	56-23-5	0.5	<0.1
5.	CHLOROBENZENE	108-90-7	100	<1.0
6.	CHLOROFORM	67-66-3	6.0	<1.0
7.	METHYL ETHYL KETONE	78-93-3	200	<1.0
8.	TETRACHLOROETHYLENE	127-18-4	0.7	<0.1
9.	TRICHLOROETHYLENE	79-01-6	0.5	<0.1
10.	VINYL CHLORIDE	75-01-4	0.2	<0.1

TCLP SIMVOLATILES ORGANIC ANALYSIS

	COMPOUND	CASNO	MAX.LEVEL mg/l	AMOUNT mg/l
1.	2,4,5-TRICHLOROPHENOL	95-95-4	400	<1.0
2.	2,4,6-TRICHLOROPHENOL	88-06-2	2.0	<1.0
3.	CRESOL-TOTAL		200	<1.0
4.	O-CRESOL	95-48-7	200	<1.0
5.	M-CRESOL	108-39-4	200	<1.0
6.	P-CRESOL	106-44-5	200	<1.0
7.	PENTACHLOROPHENOL	87-86-5	100	<1.0
8.	1,4-DICHLOROBENZENE	106-46-7	7.5	<1.0
9.	2,4-DINITROTOLUENE	121-14-2	0.13	<0.1
10.	HEXACHLOROBENZENE	118-74-1	0.13	<0.1
11.	HEXACHLOROBUTADIENE	87-68-3	0.50	<0.1
12.	HEXACHLOROETHANE	67-72-1	3.0	<1.0
13.	NITROBENZENE	98-95-3	2.0	<1.0
14.	PYRIDINE	110-86-1	5.0	<1.0

TCLP METALS ANALYSIS

	COMPOUND	CASNO	MAX.LEVEL mg/l	AMOUNT mg/l
1.	ARSENIC	7440-38-2	5.0	
2.	BARIUM	7440-39-3	100	
3.	CADMIUM	7440-43-9	1.0	
4.	CHROMIUM	7440-47-3	5.0	
5.	LEAD	7439-92-1	5.0	
6.	MERCURY	7439-97-6	0.20	
7.	SELENIUM	7782-49-2	1.00	
8.	SILVER	7440-22-4	5.00	

TIM CORUM, ORGANIC MANAGER

TED YEN, INORGANIC MANAGER

Table C.3
Toxicity Characteristic Leaching Procedure for Organic Contaminants Found in Sample SB Prior to Treatment

NAVY PUBLIC WORKS CENTER
CODE 330, ENVIRONMENTAL LAB
ATTN: GREGORY GEBHARDT

DATE RECEIVED : 6- 5-92
DATE OF REPORT: 6-16-92
CONTRACT NO: N62755-87-D-2819

D.O.NO. : 265-1
SAMPLE ID: 92-04232

QA/QC OFFICER

TCLP VOLATILE ORGANIC ANALYSIS

	COMPOUND	CASNO	MAX.LEVEL mg/l	AMOUNT mg/l
1.	1,1-DICHLOROETHYLENE	75-35-4	0.7	<0.1
2.	1,2-DICHLOROETHANE	107-06-2	0.5	<0.1
3.	BENZENE	71-43-2	0.5	<0.1
4.	CARBON TETRACHLORIDE	56-23-5	0.5	<0.1
5.	CHLOROBENZENE	108-90-7	100	<1.0
6.	CHLOROFORM	67-66-3	6.0	<1.0
7.	METHYL ETHYL KETONE	78-93-3	200	<1.0
8.	TETRACHLOROETHYLENE	127-18-4	0.7	<0.1
9.	TRICHLOROETHYLENE	79-01-6	0.5	<0.1
10.	VINYL CHLORIDE	75-01-4	0.2	<0.1

TCLP SIMVOLATILES ORGANIC ANALYSIS

	COMPOUND	CASNO	MAX.LEVEL mg/l	AMOUNT mg/l
1.	2,4,5-TRICHLOROPHENOL	95-95-4	400	<1.0
2.	2,4,6-TRICHLOROPHENOL	88-06-2	2.0	<1.0
3.	CRESOL-TOTAL		200	<1.0
4.	O-CRESOL	95-48-7	200	<1.0
5.	M-CRESOL	108-39-4	200	<1.0
6.	P-CRESOL	106-44-5	200	<1.0
7.	PENTACHLOROPHENOL	87-86-5	100	<1.0
8.	1,4-DICHLOROBENZENE	106-46-7	7.5	<1.0
9.	2,4-DINITROTOLUENE	121-14-2	0.13	<0.1
10.	HEXACHLOROBENZENE	118-74-1	0.13	<0.1
11.	HEXACHLOROBUTADIENE	87-68-3	0.50	<0.1
12.	HEXACHLOROETHANE	67-72-1	3.0	<1.0
13.	NITROBENZENE	98-95-3	2.0	<1.0
14.	PYRIDINE	110-86-1	5.0	<1.0

TCLP METALS ANALYSIS

	COMPOUND	CASNO	MAX.LEVEL mg/l	AMOUNT mg/l
1.	ARSENIC	7440-38-2	5.0	
2.	BARIUM	7440-39-3	100	
3.	CADMIUM	7440-43-9	1.0	
4.	CHROMIUM	7440-47-3	5.0	
5.	LEAD	7439-92-1	5.0	
6.	MERCURY	7439-97-6	0.20	
7.	SELENIUM	7782-49-2	1.00	
8.	SILVER	7440-22-4	5.00	

TIM CORUM, ORGANIC MANAGER

TED YEN, INORGANIC MANAGER

Table C.4
Total Suspended Solids in Bilge Waste Prior to Treatment

Total Suspended Solids (mg/l)	
USS *Cushing*	USS *Willamette*
126	94
104	122
115 (avg.)	108 (avg.)

APPENDIX D
HYDRAULIC CALCULATIONS FOR DIAMETER OF FIXED PIPE COLLECTION SYSTEM

Bravo Piers

Length is 8250 ft.
Desired velocity of flow is 5 - 7 fps
Start of pier:

Flow-

Bilge waste flow (Q) = 200 gpm = 0.4456 cfs
Adjustment factor (not all ships discharge simultaneously) = 0.31
"Cushion" factor = 1.30
Adjusted flow = (0.446 cfs) x (0.31) x (1.3)
= 0.18 cfs

Manning's Nomograph-

Use 5 fps for minimum slope.
Try 3" diameter: Slope too steep for length
Try 6" diameter: Slope too steep
Try 10" diameter: Slope too steep
Try 18" diameter: Slope O.K.
18" Diameter at 5 fps implies 9 cfs capacity.

End of pier:

Flow-

Bilge waste flow (Q) = 2200 gpm = 4.90 cfs
Adjustment factor (not all ships discharge simultaneously) = 0.31
"Cushion" factor = 1.30
Adjusted flow = (4.9 cfs) x (0.31) x (1.3)
= 1.98 cfs, say 2 cfs

Manning's Nomograph

Same results as above, use 18" diameter

Mike Piers

Length is 2000 ft.
Desired velocity of flow is 5 - 7 fps
Start of pier:

Flow-

Bilge waste flow (Q) = 200 gpm = 0.4456 cfs
Adjustment factor (not all ships discharge simultaneously) = 0.31
"Cushion" factor = 1.30
Adjusted flow = (0.446 cfs) x (0.31) x (1.3)
= 0.18 cfs

Manning's Nomograph-

Use 5 fps for minimum slope.
Try 3" diameter: Slope too steep for length
Try 6" diameter: Slope too steep
Try 10" diameter: Slope O.K.
10" Dia. at 5 fps implies 2.7 cfs capacity.

End of pier:

Flow-

Bilge waste flow (Q) = 600 gpm = 1.34 cfs
Adjustment factor (not all ships discharge simultaneously) = 0.31
"Cushion" factor = 1.30
Adjusted flow = (1.34 cfs) x (0.31) x (1.3)
= 0.54 cfs, say 0.6 cfs

Manning's Nomograph

Same results as above, use 10" diameter

Kilo Piers

Length is 4250 ft.
Desired velocity of flow is 5 - 7 fps
Start of pier:

Flow-

Bilge waste flow (Q) = 100 gpm = 0.2228 cfs
Adjustment factor (not all ships discharge simultaneously) = 0.31
"Cushion" factor = 1.30
Adjusted flow = (0.223 cfs) x (0.31) x (1.3)
= 0.09 cfs

Manning's Nomograph-

Use 5 fps for minimum slope.
Try 3" diameter: Slope too steep for length
Try 6" diameter: Slope too steep
Try 10" diameter: Slope O.K.
10" Dia. at 5 fps implies 2.7 cfs capacity.

End of pier:

Flow-

Bilge waste flow (Q) = 400 gpm = 0.9 cfs
Adjustment factor (not all ships discharge simultaneously) = 0.31
"Cushion" factor = 1.30
Adjusted flow = (0.9 cfs) x (0.31) x (1.3)
= 0.36 cfs, say 0.4 cfs

Manning's Nomograph

Same results as above, use 10" diameter

Hotel Pier

Length is 3750 ft.
All other results same as Kilo pier.

Pumps Required

Assume a maximum pipe depth of 6 ft. Therefore the Bravo pier (slope = 0.007) will require 9 pumps; the Mike pier will require 4; the Kilo pier will require 10, and the Hotel pier will require 9 pumps.

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Thesis
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